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A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions

Vol. 2

**mandatory inspection/maintenance
systems study**

TRW Systems Group

prepared for

Environmental Protection Agency

JULY 1972

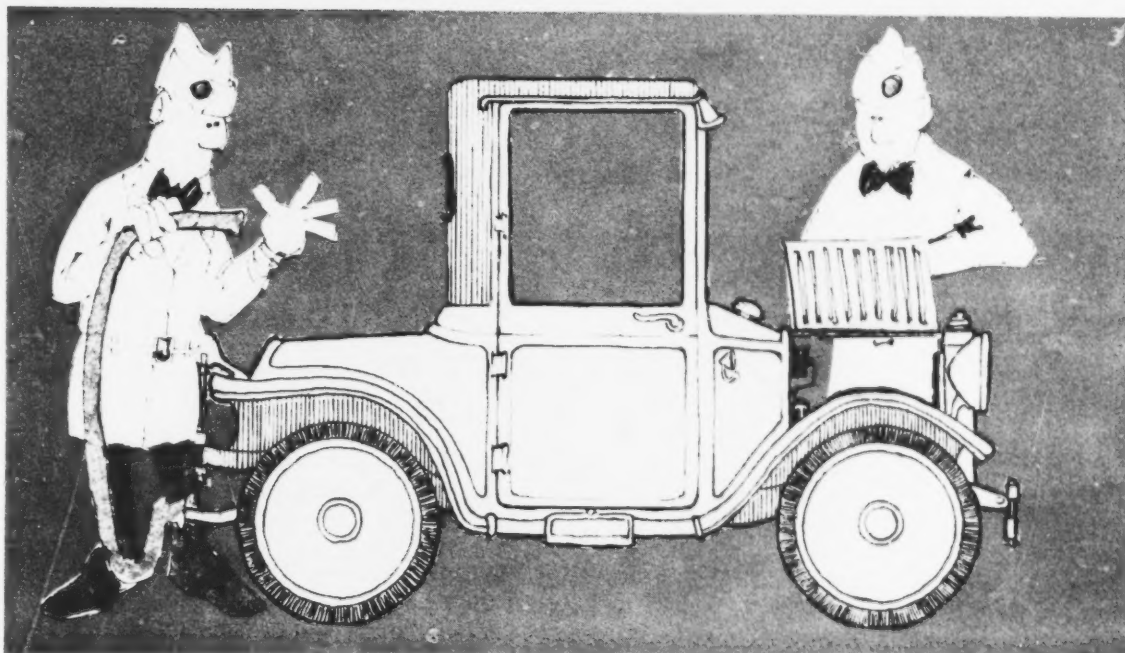
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A Study of PB 220 727
Mandatory Engine Maintenance
for Reducing Vehicle Exhaust Emissions

Volume II. Mandatory Inspection/Maintenance
Systems Study



Year End Report
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PREFACE

This report, "A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions," consists of six volumes. The following are the subtitles given for each volume:

- Executive Summary, Volume I
- Mandatory Inspection/Maintenance Systems Study, Volume II
- A Documentation Handbook for the Economic Effectiveness Model, Volume III
- Experimental Characterization of Vehicle Emissions and Maintenance States, Volume IV
- Experimental Characterization of Service Organization Maintenance Performance, Volume V
- A Comparison of Oxides of Nitrogen Measurements Made With Chemiluminescent and Non-Dispersive Radiation Analyzers, Volume VI

The first volume summarizes the general objectives, approach and results of the study. The second volume presents the results of the mandatory inspection/maintenance system study conducted with a computerized system model which is described in Volume III. The experimental programs conducted to develop input data for the model are described in Volume IV (Interim Report of 1971-72 Test Effort) and V. Volume VI presents comparative measurements of NO and NO_x using chemiluminescence and NDIR/NDUV instruments and differences in these measurements are examined.

The work presented herein is the product of a joint effort by TRW Systems Group and its subcontractor, Scott Research Laboratories. TRW, as the prime contractor, was responsible for overall program management, experimental design, data management and analysis, and the economic effectiveness study. Scott acquired and tested all of the study vehicles. Scott also provided technical assistance in selecting emission test procedures and in evaluating the test results.

A STUDY OF MANDATORY ENGINE MAINTENANCE PROCEDURES FOR REDUCING VEHICLE EXHAUST EMISSIONS

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1.0 INTRODUCTION AND SUMMARY

This report summarizes the results obtained during the first year of the Extended Phase I CRC Emission Test Program. The main focus of this study was to assess the feasibility of reducing exhaust emissions through a program of mandatory inspection and maintenance. The basic differences between this analysis and one presented in the Interim Report [1] involve the use of an improved experimental data base and refinements in the Economic Effectiveness Model. A detailed account of the derived emission data sets is presented in Volumes IV and V. A corresponding discussion of the structure and elements of the model is given in the Economic Effectiveness Model Handbook (Volume III).

The study was conducted using the Economic Effectiveness Computer model program which is capable of predicting the emissions changes and costs associated with a wide range of inspection and maintenance procedures. The model has been designed to consider the following factors in evaluating inspection/maintenance procedures:

- the extent and frequency of inspection and maintenance procedures
- the quantitative inspection criteria to be used in identifying and rejecting malfunctioned vehicles
- the reliability with which service organizations perform diagnosis and repair, and the resulting actual costs of maintenance
- the deterioration of engine adjustments with vehicle usage
- the time dependency of the mix of uncontrolled and emission controlled vehicles resulting from the attrition of older vehicles and the introduction of new vehicles
- the existing and required air quality of regions under study
- the time and cost of selective maintenance operations as performed in a certified garage
- the design and cost of state inspection lanes including their number, size and location
- the user time spent in traveling to and waiting at inspection and maintenance stations
- the impact of start-up costs for state lane inspection strategies.

To support the model, data have been obtained experimentally which define the general maintenance state of large vehicle populations, the sensitivity of exhaust emissions to engine malfunctions, and the rate with which engine parameters deteriorate.

Two basic types of inspections were evaluated:

- Direct diagnosis of engine parameters (maladjustments and malfunctions) using conventional or more sophisticated garage-type equipment
- Inference of engine parameter deviations from manufacturer's specification using measurements of exhaust emission levels (signatures) at different engine loading conditions.

The results of the study reported herein using emission reductions based upon the Federal 1972 Emission Test Procedures support the general conclusions with regard to Los Angeles which were presented in the Interim Report. Subject to limitations in the model and its supporting data sets which are described in detail in the various volumes of this report, the following specific conclusions were drawn:

- The most cost-effective inspection interval is approximately yearly regardless of the inspection/maintenance procedures applied.
- Inspection procedures performed in a state lane using the measurement of exhaust emissions under load are generally more cost-effective than those performed in franchised garages using conventional diagnostic instruments, but produce smaller emission reductions.
- A statistical analysis of the emission reductions for the baseline and test fleets has revealed that the predicted differences in mean emission levels is usually significant at greater than the 90 percent level of confidence. Furthermore, the emission reductions for procedures employing extensive maintenance which are statistically significant at a 95 percent level of confidence are nearly 50 percent of the predicted mean values.
- The cost-effectiveness and amount of required maintenance is highly dependent on the demographic characteristics and air quality needs of a given region.
- The figure of merit (annularized discounted total program cost divided by the weighted five-year reductions of emissions) is very sensitive to the relative weighting assigned to HC, CO and NO_x emission reductions and to the extent of imposed maintenance.

- The figure of merit and emission reductions are highly sensitive to the rate of maintenance deterioration, the effectiveness of voluntary maintenance and the reliability of the repair.
- Emission reductions are most sensitive to the inspection approach used to reject vehicles and to the extent of the imposed maintenance.

The above conclusions are based upon the data presently available. Study results will be upgraded and revised in a final report at the conclusion of the continuing engine parameter deterioration experiment. The primary purpose of this report is to provide general guidance for those states contemplating inspection/maintenance programs as part of their implementing strategy for meeting the new federal air quality standards. Those states actually implementing programs such as described in this report should consider performing pilot studies on a small scale to verify that the estimated results presented herein can be achieved within the framework of their specific requirements and within the capability of their existing maintenance organizations.

2.0 SYSTEM STUDY APPROACH

This section presents a discussion of strategies examined in this study and a description of the methodology used for accessing their feasibility when used in a mandatory program of vehicle inspection/maintenance.

The revised economic-effectiveness model (Volume III-A Documentation Handbook for the Economic Effectiveness Model, 1 May 1972) and the recently augmented data base (Volumes IV and V) was used to evaluate the performance of each of the previously studied inspection/maintenance procedures. As in the prior program, two general inspection alternatives were examined:

- an engine parameter inspection followed, as necessary, by specific maintenance
- an exhaust emission inspection followed by further diagnosis and corrective maintenance of the rejected vehicles.

Since each of these two basic approaches contains a large number of possible variations, specific candidate strategies were selected in advance of the actual analysis. The results of previous studies were used to guide this selection. Table 2-1 is a summary of the inspection/maintenance alternatives examined.

These alternatives reflect the importance of inspecting and maintaining three categories of engine maladjustments and malfunctions:

- 1) idle related adjustments
- 2) ignition components affecting misfire or spark advance (NO_x control)
- 3) induction system components affecting carbureted fuel to air ratio.

The idle related adjustments (fuel to air, timing and speed) involve labor only, are economical to repair and can be selectively manipulated to influence all three exhaust emission species. Ignition related components primarily influence HC emissions, although NO_x emissions are also strongly affected by spark timing. The cost of repairing these items is distributed about equally between labor and parts. Induction system components failures (PCV valve, air cleaner, air pump and choke system)

TABLE 2-1

Inspection/Maintenance Procedures Studied

<u>Engine Parameter Diagnostic Strategy</u>	<u>Inspection/Maintenance Procedure</u>
1) Idle (Franchised Garage)	Inspect and adjust ICO, rpm, timing
2) Extensive A (Franchised Garage with Dynamometer)	Inspect and adjust ICO, rpm, timing Repair misfire and NO _x control
3) Extensive B (Franchised Garage with Dynamometer)	Inspect and adjust ICO, rpm, timing, repair misfire, air pump, PCV valve, air cleaner, NO _x control, choke system
<u>Emission Signature Analysis Strategy</u>	
1) Idle (State Lane)	Measure ICO, IHC; adjust ICO, rpm, timing
2) Extensive A (State Lane Emission Under Load)	Measure ICO, IHC, LHC Adjust ICO, rpm, timing Repair misfire and NO _x control
3) Extensive B (State Lane Emission Under Load)	Measure ICO, IHC, LHC, LCO Adjust ICO, rpm, timing Repair misfire, PCV valve, air cleaner

ICO, idle CO emission measurement
 IHC, idle HC emission measurement
 LHC, loaded mode HC emission measurement, 45/49 MPH Key Mode
 LCO, loaded mode CO emission measurement, 45/49 MPH Key Mode

primarily affect CO emissions and to a lesser degree HC and NO_x. Repair costs for these items tend to be largely determined by the cost of replacement parts, although labor costs for air pump and choke maintenance can be appreciable.

Clearly, the maintenance of any combination of these three categories of malfunctions may be desirable depending on regional air quality requirements. In order to evaluate inspection and maintenance alternatives systematically these three categories of malfunctions have been used to define the following three maintenance options: 1) idle adjustments which are made primarily to reduce CO emissions, 2) extensive "A" maintenance consisting of idle adjustments and the repair of the ignition component failures which is performed to reduce both HC and NO_x emissions; and 3) extensive "B" maintenance which adds the repair of induction related malfunctions for further CO control to the extensive "A" maintenance treatment.

The engine parameter malfunctions within these maintenance options can be diagnosed using conventional, commercially available equipment and procedures or inferred indirectly from an exhaust mode emission measurement. Appropriate emissions signatures (modes) must be selected when the latter approach is used. This selection process is described in Volume IV and the selected modes are those summarized in Table 2-1. It was generally found that using a single emission mode to identify a specific malfunction was as effective as using multiple emission modes. Exceptional cases were the diagnosis of air cleaner and PCV valve malfunctions where vehicle rejections based upon high emissions in two engine operating modes, i.e., CO and HC under load, yielded slightly improved failure diagnosis (5-10 percent). This situation however did not occur consistently across all vehicle emission control categories or regions. To simplify both the computer model and the implementation of strategies selected by the model, only single emission modes were used to identify specific malfunctions. Only three emission modes which identify the large number of actual failures over a wide range of mode emission cut off levels was selected for the system study.

This study was performed in three parts as described in the following sections.

- 1) Optimization of the six inspection/maintenance procedures described in Table 2-1 with regard to the specific components within each subsystem to be maintained and their associated rejection criteria.
- 2) An evaluation of the basic study ground rules and assumptions to determine their impact on procedure effectiveness.
- 3) An assessment of the regional implications of vehicle inspection/maintenance. This analysis contrasts the effectiveness of the candidate procedure between two urban regions with differing air quality problems.

A five-year time period was studied to determine if predicted emission levels stabilized at the end of that period. Projections of the performance of mandatory vehicle inspection/maintenance programs were limited to no more than five years because of:

- uncertainty in estimating the effects of major engine malfunctions which may occur beyond that period
- lack of experimental emission time history data beyond 50,000 miles (i.e., approximately five years)
- inability to project the impact of new control technology.

Since issuing the interim report, the Economic Effectiveness Model has been modified to improve its ability to predict the impact of the various procedures on the total population. The more salient model improvements are as follows:

- 1) Characterization of the vehicle population by three emission control classes: uncontrolled vehicles (pre 1966), controlled vehicles (1966-1970) and post 1970 vehicles (NO_x control).
- 2) Incorporation of a vehicle attrition algorithm for estimating changes in vehicle population distributions over time for the three emission control classifications. The algorithm presently characterizes all new vehicles entering the population by the post 1970 emissions data.
- 3) Introduction of the influence coefficients for adjustment interactions and the addition of three new engine parameters (NO_x control device, choke system) bring the total parameter set^x to ten. The influence coefficients for interactions relate changes in emissions species to the adjustment and/or repair of two engine parameters.

- 4) The use of tabular engine parameter and mode emission distributions in lieu of the analytic descriptions used previously. This provides for a more accurate, although more complex, treatment of these basic data.
- 5) Integration of measured garage efficiency performance into maintenance effectiveness analysis.
- 6) Addition of franchised garage inspection costs, the cost of unnecessary maintenance, and state lane inspection training and processing costs into the economic analysis.

In addition to these refinements, the Economic Effectiveness Model now includes the following data sets for all three controlled fleets:

- 1) Mass and key mode primary and interaction influences coefficients (orthogonal experiments)
- 2) Engine parameter and emission deterioration rates (deterioration experiments)
- 3) Engine parameter and mode emission distributions (Los Angeles and Detroit survey)
- 4) Initial vehicle emission levels (Test IA, deterioration experiment)
- 5) Franchised garage maintenance effectiveness factors (garage performance experiment)
- 6) Revised operating and capital cost data (garage performance experiment)
- 7) Parameter failure rates and mean values of parameters for the failed and passed vehicle populations when various mode emission inspection criteria are applied (cutpoint analysis of deterioration experiment data).

These model refinements and data additions, when taken collectively, constitute the Revised 1972 Economic Effectiveness Model. Before examining results derived using this model, it might be appropriate to review several of the basic ground rules used in constructing the model:

- All mass and mode emission levels and emission reduction percentages are reported as average values for the entire vehicle population.
- Pass/fail criteria for each inspection and maintenance strategy are optimized for the first inspection interval (year zero) and remain invariant with time.
- Maintenance of engine malfunctions and maladjustments which is not included by the enforced maintenance procedure is assumed to be performed voluntarily by the owner.

- Estimated mean emission reductions are based on measurements made with the 1972 Federal Test Procedure.
- Parameter deterioration rates, influence coefficients and extent of voluntary maintenance are assumed to be the same throughout the country.
- The criteria used in passing or failing vehicles during inspection involve the state of engine adjustments and/or mode emission levels and not composite mass emission levels.

The reader is encouraged to review Volume III for a more detailed discussion of the basic modeling approach and the actual and implied assumptions which are a basic part of the economic effectiveness model.

3.0 SELECTION OF OPTIMUM PROCEDURES

The upgraded computer model was first used to evaluate the economic effectiveness of the six basic inspection/maintenance procedures previously described. The Los Angeles basin was selected for this evaluation because: 1) the experimental data used in the model were developed in the Los Angeles area; 2) the region suffers from chronic air pollution in the form of photochemical smog to which the automobile is a significant contributor.

The basic performance indicator used in ranking the various strategies is the program figure of merit. It is calculated from aggregated values of emissions reductions and system cost as shown in Equation 3-1.

$$FM = \frac{\text{annularized, discounted total program cost}}{\sum_{i=1}^3 W_i * (E_{vi} - E_{mi})} \quad (3-1)$$

where:

FM, figure of system merit for a specific procedure, \$/ton

W_i , normalized weighting factors for each emission species

E_{vi} , integrated emission level for each emission specie for a baseline (voluntary maintenance) population

E_{mi} , integrated emission level for each emission specie from a population subject to the specified mandatory inspection/maintenance procedures

Weighting factors selected for the Los Angeles Basin are:

$$W_{HC} = 0.6$$

$$W_{CO} = 0.1$$

$$W_{NO_x} = 0.3$$

The figure of merit has been evaluated using two different measures of emission reduction which depend upon the time frame of the evaluation as well as based upon the emission reduction which can be shown statistically to be achievable at a specified level of confidence. Three figures of merit therefore are calculated based upon:

- 1) The integrated average emission reductions relative to the baseline population achieved over a five year period
- 2) Emission reduction achieved relative to the baseline population at the end of the fifth year
- 3) Statistically significant emission reduction achieved relative to the baseline population at the end of the fifth year.

The utility of these three figures of merit is that they permit the ranking of the procedures to be based on either average performance results, or on the results obtained at the end of the program's time horizon. One or both of these criteria may be employed, depending on the immediate severity of a regional air pollution problem. System performance can also be measured by separately examining the resulting emission reductions and inspection costs derived for each candidate strategy.

3.1 PROCEDURES PERFORMANCE COMPARISON

Table 3-1 presents a comparison of optimal system performance derived from this study with that presented in the interim report. As can be seen, the program figures of merit for all strategies studied in the current analysis has become dramatically poorer (increased) relative to the interim results. In some instances (engine parameter extensive A maintenance) the figure of merit has risen over sevenfold. This degradation in system performance can be attributed directly to higher program costs, ineffective garage maintenance and lower emission deterioration rates.

A comparison of the cost per vehicle for the two analyses reveals the impact on the current results of the upgraded inspection/maintenance cost data and the training costs associated with a state lane inspection. The

TABLE 3-1 COMPARISON OF INTERIM AND YEAR-END OPTIMAL RESULTS
FOR BASIC INSPECTION/MAINTENANCE PROCEDURES

INSPECTION/MAINTENANCE PROCEDURES	FIGURE OF MERIT \$/TON+++		COST PER VEHICLE		EMISSION REDUCTIONS, PERCENT			NO _x		
	I	F	I	F	HC	CO	I	F	I	F
ENGINE PARAMETER INSPECTION										
1. IDLE (FRANCHISED)	200	950	3.00	4.00	4.0	2.4	6.0	2.6	6.0	-0.2
2. EXTENSIVE A+ (FRANCHISED)	230	1780	7.00	11.30	21.0	10.8	6.0	2.6	6.0	-0.2
3. EXTENSIVE B++ (FRANCHISED)	350	1975	13.50	24.80	23.0	11.6	12.0	5.1	3.0	-1.1
EXHAUST EMISSION INSPECTION										
4. IDLE (STATE LANE)	225	730	1.90	3.20	0.0	1.5	6.0	2.9	2.0	-0.0
5. EXTENSIVE A+ (STATE LANE)	190	1305	2.50	10.10	9.0	7.9	6.0	2.9	2.0	-0.0
6. EXTENSIVE B++ (STATE LANE)	320	1475	5.75	12.35	9.0	8.1	8.0	3.4	0.0	-0.3

+ IDLE PLUS IGNITION TUNEUP, WITH DYNAMOMETER

++ IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

+++ L.A. BASIN WEIGHTING FUNCTION

I: INTERIM REPORT RESULTS

F: YEAR END REPORT RESULTS

most significant change occurred for the procedure involving an emission inspection followed by an extensive "A" maintenance treatment where the cost per vehicle (based on the total population) increased nearly four-fold.

The percent emission reductions reported for the present study averaged approximately one-half those reported earlier. Exceptions were NO_x reductions for both inspection strategies and HC reductions for the emission inspection approach. This decrease in exhaust emission reductions is due primarily to the ineffectiveness of maintenance. CO emission reductions especially are not as great because of low effectiveness in maintaining those parameters influencing this emission. The poorer performance in reducing NO_x emissions is due to improper adjustment of basic timing for several types of controlled vehicles. The general consistency in HC reductions between the two studies for the emission inspection strategy is a result of similar rejection rates for engine misfire and the highly effective repair of this malfunction.

A complete set of results from the current analysis results is given in Table 3-2. The engine parameter inspection strategy is seen to be less cost effective across all maintenance treatments than is the emission inspection procedure. This occurs even though the engine parameter inspection strategy produces larger emission reductions.

Because the magnitude and sign of the influence coefficients varied between the three classes of vehicles studied and because the costs of repairing some of the parameters were larger than others, a slightly different approach was used on this study to define optimal strategies. In previous analyses, all engine parameters included in a particular maintenance procedure were inspected in all vehicles and were maintained on those cars which did not satisfy specified pass/fail criteria. It has now been recognized that while this approach is conceptually correct, it does not necessarily lead to the most cost effective program. For example, the incorporation of the vacuum choke kick parameter has a relative small effect on emission reduction (due, in part, to the low reliability of maintenance) while the costs of its inspection and maintenance are relatively high. Greater emission reduction can be achieved

TABLE 3-2 COMPARISON OF OPTIMAL RESULTS FOR BASIC INSPECTION/MAINTENANCE PROCEDURES

INSPECTION/MAINTENANCE PROCEDURES	FIGURE OF MERIT \$/TON ⁺⁺⁺			COST PER VEHICLE		EMISSION REDUCTIONS, PERCENT		
	A	B	C	D	E	HC	CO	NO
ENGINE PARAMETER INSPECTION								
1. IDLE (FRANCHISED)	950	420	5145	4.00	4.50	2.4	2.6	-0.2
2. EXTENSIVE A ⁺ (FRANCHISED)	1780	645	1020	11.30	22.40	10.8	2.6	-0.2
3. EXTENSIVE B ⁺⁺ (FRANCHISED)	1975	695	1070	24.80	29.20	11.6	5.1	-1.1
EXHAUST EMISSION INSPECTION								
4. IDLE (STATE LANE)	730	340	0	3.20	4.10	1.5	2.9	-0.0
5. EXTENSIVE A ⁺ (STATE LANE)	1305	470	915	10.10	17.50	7.9	2.9	-0.0
6. EXTENSIVE B ⁺⁺ (STATE LANE)	1475	510	1045	12.35	21.35	8.1	3.4	-0.3

⁺ IDLE PLUS IGNITION TUNEUP, WITH DYNAMOMETER

⁺⁺IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

⁺⁺⁺L. A. BASIN WEIGHTING FUNCTION

- A. Computed over five year period.
- B. Computed at end of last interval.
- C. Based on statistically significant emissions reductions for last interval.
- D. Based on total vehicle population.
- E. Based on maintained portion of vehicle population.

at lower cost by merely making the pass/fail criteria for air cleaner more restrictive. This revised approach has resulted in eliminating the inspection and maintenance of some parameters for each of the fleets in order to achieve an optimal program in a cost effective sense. This new approach has not, however, required modification of the basic structure of the Economic Effectiveness Model. Consequently, the implications of including all parameters in the analysis can still be studied easily.

The "best" procedure (i.e., the one having the lowest average figure of merit of 730) is an idle CO emission inspection followed by the adjustment of the carburetor idle fuel to air ratio. Timing is also to be adjusted on the 1966-70 emission controlled vehicles, but was found not to be cost-effective to maintain on the other two vehicle classes. This results from the fact that retarding basic timing substantially increases CO emissions on precontrolled and post 1970 vehicles, thus cancelling the beneficial effects on the figure of merit of reduced NO_x and HC emissions. (The influence coefficient for CO with respect to timing is nearly five times as large for the post 1970 vehicles as for the 1966-70 emission controlled vehicles.) It should be noted that this "best" procedure does not greatly reduce exhaust emissions and, therefore, may be of little practical interest.

The next two most cost effective procedures, an inspection of the idle adjustments followed by their maintenance and an emission inspection followed by extensive "A" maintenance, have figures of merit of 950 and 1305, respectively. The emission inspection procedure is over three times more effective in reducing HC, has little additional influence on CO, and costs 2.5 times as much as the idle parameter inspection and maintenance procedure. The emission inspection procedure also has the lowest figure of merit (915) of all procedures when calculated using the emission reduction at the end of the fifth year estimated at the 90 percent confidence level. Because of this favorable figure of merit and the large HC emissions reductions achieved (8% average and 16% in the fifth year), this procedure would be attractive for areas with severe photochemical smog. It will be shown in the sensitivity analysis, Section 4.0, that if CO emissions are completely ignored, greater HC emissions can be obtained without degrading the figure of merit by maintaining those malfunctions which result in advanced ignition timing.

The smaller incremental emission reductions effected with the emission inspection procedure followed by the more extensive "B" maintenance, result because of the relatively poor ability of this inspection procedure to detect component failures which affect induction system performance. Indeed, virtually all of the procedures investigated achieved only modest CO reductions and had no influence on NO_x. The largest CO reduction is achieved with a direct parameter inspection procedure and "B" maintenance. Average and fifth year CO reductions are 5.3 and 8.4, respectively. The generally poor performance in reducing CO emissions is due in large part to poor garage performance in maintaining the induction system. The average maintenance effectiveness for the induction system repair is approximately 50 percent compared to 75 percent for the ignition system and 80 percent for the idle adjustment parameters.

Two cost figures are presented in Table 3-2, one based upon prorating the cost of inspection and maintenance over the total vehicle population and the other upon distributing inspection costs over the entire vehicle population while prorating maintenance costs to the rejected portion of the population only. The overall higher program costs can be attributed to the cost of unnecessary repairs and to the increased information processing costs that have been included in the economic analysis. These cost projections appear consistent with estimates made from a number of ongoing experimental and operational programs.

Absolute values for emission reductions instead of percent emission reductions can be used as the criteria for evaluating the performance of alternate inspection and maintenance procedures. Table 3-3 presents the emission reductions in tons per day predicted by the computer model for the six basic inspection and maintenance procedures. These are the average emission reductions achieved over a five year program time span during which the automobile population

TABLE 3.3 AVERAGE ABSOLUTE MASS EMISSION REDUCTIONS
FOR SELECTED PROCEDURES

Inspection/Maintenance Procedure	Average Reductions+++			
	HC	CO	NO	
		Tons/Day		
ENGINE PARAMETER INSPECTION				
1. Idle (Franchised)	19.6	255.	-0.99	
2. Extensive A+ (Franchised)	87.2	255.	-0.91	
3. Extensive B++ (Franchised)	94.3	520.	-5.37	
EXHAUST EMISSION INSPECTION				
4. Idle (State Lane)	12.2	289.	-0.32	
5. Extensive A+ (State Lane)	63.8	289.	-0.32	
6. Extensive B++ (State Lane)	65.0	339.	-1.67	

+ Idle plus ignition with dynamometer.

++ Idle plus ignition and induction tuneup with dynamometer.

+++ Negative values indicate an actual increase over the baseline.

grows from four million to over 4.6 million cars. The characteristics of the vehicle population are more completely described in a following section of this report.

As would be expected the largest absolute value of emission reduction is achieved for CO. It is noted on the other hand that CO percent reductions are consistently smaller than HC percent emission reductions. Only a two to one variation of CO absolute emission reduction is seen across all procedures while a five to one variation in HC emission reduction is predicted.

If absolute emission reductions are used in the program figure of merit with the L.A. Basin weighting factors, then the weighted HC, CO and NO_x emission reductions are 13.7, 25.5 and 2.99, respectively for the idle parameter inspection and maintenance treatment. The weighted CO emission reduction is considerably larger than the other terms and will strongly influence procedure selection. Clearly, the prediction of absolute values for emission reductions is also of direct importance when considering atmospheric loading and ambient air pollution concentrations.

3.2 EMISSION HISTORIES

The population weighted, average emission profiles for the two basic inspection approaches are shown in Figures 3-1 and 3-2 for idle adjustment and extensive "B" maintenance programs, respectively. These profiles reveal slightly decreasing emission levels for HC and CO and nearly constant levels for CO with time. Two opposing effects are shaping these profiles--emission increases due to engine adjustment deterioration and emission decreases due to new vehicles having lower emission levels entering the population. As previously noted, all new

AGGREGATE EMISSION TIME HISTORIES

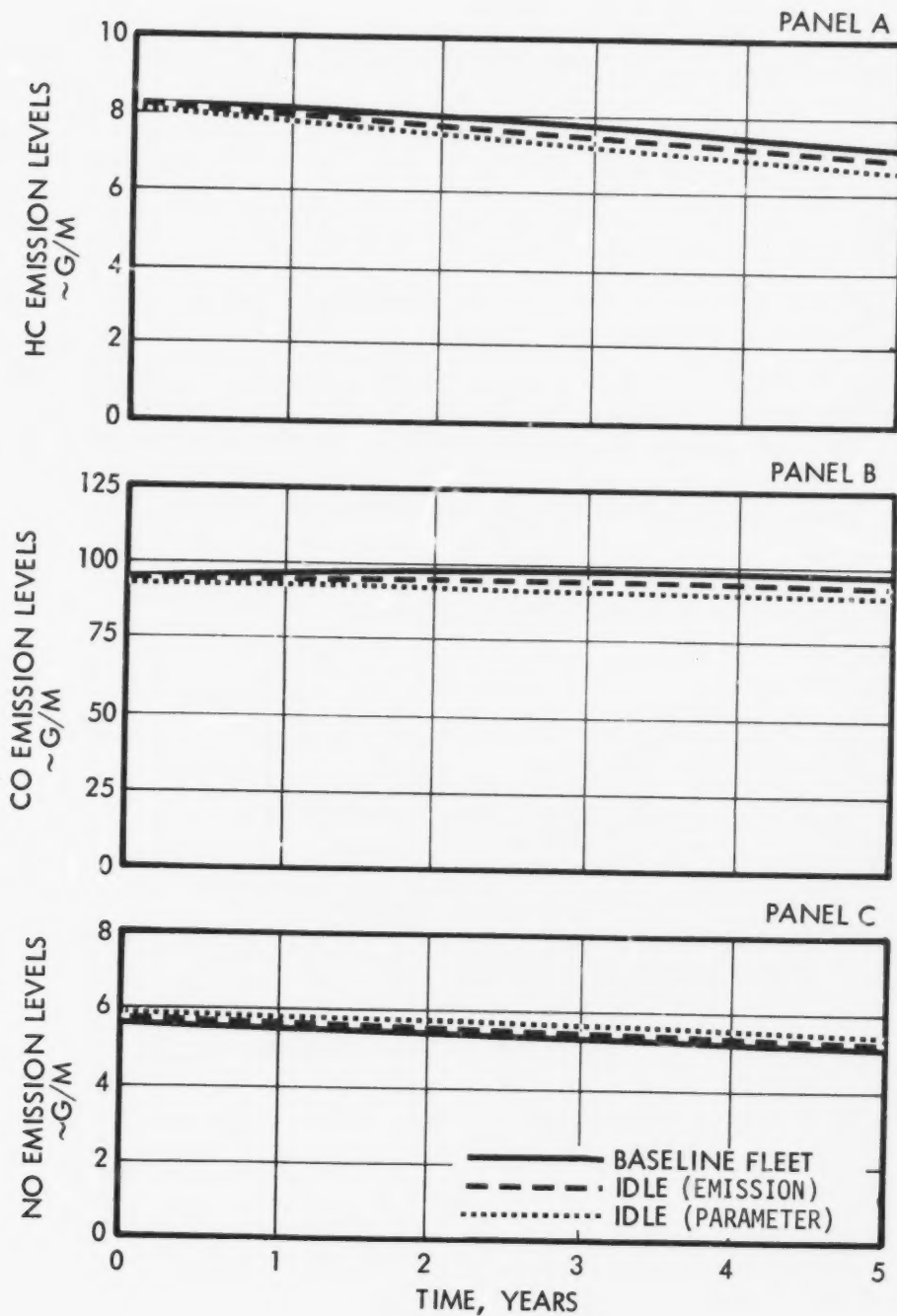


FIGURE 3-1 EMISSION TIME HISTORIES FOR IDLE MAINTENANCE TREATMENT

AGGREGATE EMISSION TIME HISTORIES

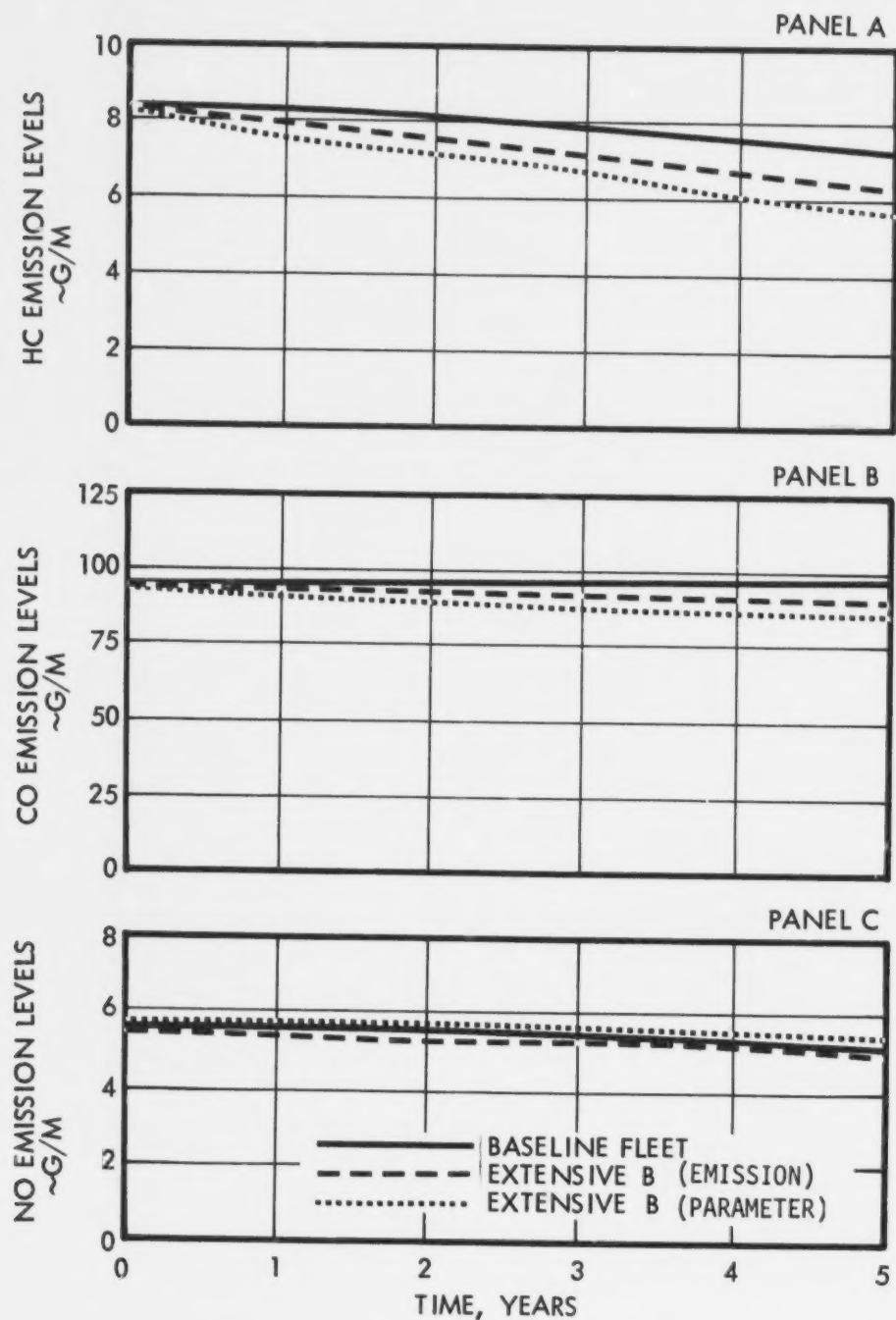


FIGURE 3-2 EMISSION TIME HISTORIES FOR EXTENSIVE B MAINTENANCE TREATMENT

vehicles entering the population are assumed to have emissions characteristics identical to the most advanced control system studies in this program (1971 California NO_x control). Therefore, the lowest possible emission values occur when the entire vehicle population is replaced with these vehicles and they are optimally maintained. At the end of the fifth year approximately 70 percent of the vehicle population are the equivalent of the 1970 NO_x controlled vehicles in varying states of deterioration.

The idle adjustment programs have their largest impact on the reduction of CO emissions and their smallest impact on NO_x. The resultant emission reductions relative to the baseline fleet have tended to stabilize by the end of the fifth year are substantially larger than for the first several years of the program.

A similar trend in emission reductions with time can be seen for the more extensive inspection/maintenance programs. Greater HC and CO emission reductions are achieved by these procedures than by the idle inspection/maintenance programs. The HC and CO emission reductions appear stable relative to the baseline after four years. The larger HC emission reductions are attributable to the significant effect of correcting misfire by maintenance of the ignition system.

Computer derived average emission profiles for the three basic emission control fleets are shown separately in Figures 3-3 and 3-4 for engine parameter diagnostic inspections followed by idle and extensive "B" maintenance, respectively. The substantial impact of correcting the higher frequencies of misfire on the older precontrolled vehicles can be seen by contrasting HC emissions between Figures 3-3 and 3-4. The emissions for all three fleets undergoing extensive maintenance are also seen to be much more stable over time.

CONTROL TYPE EMISSION TIME HISTORIES

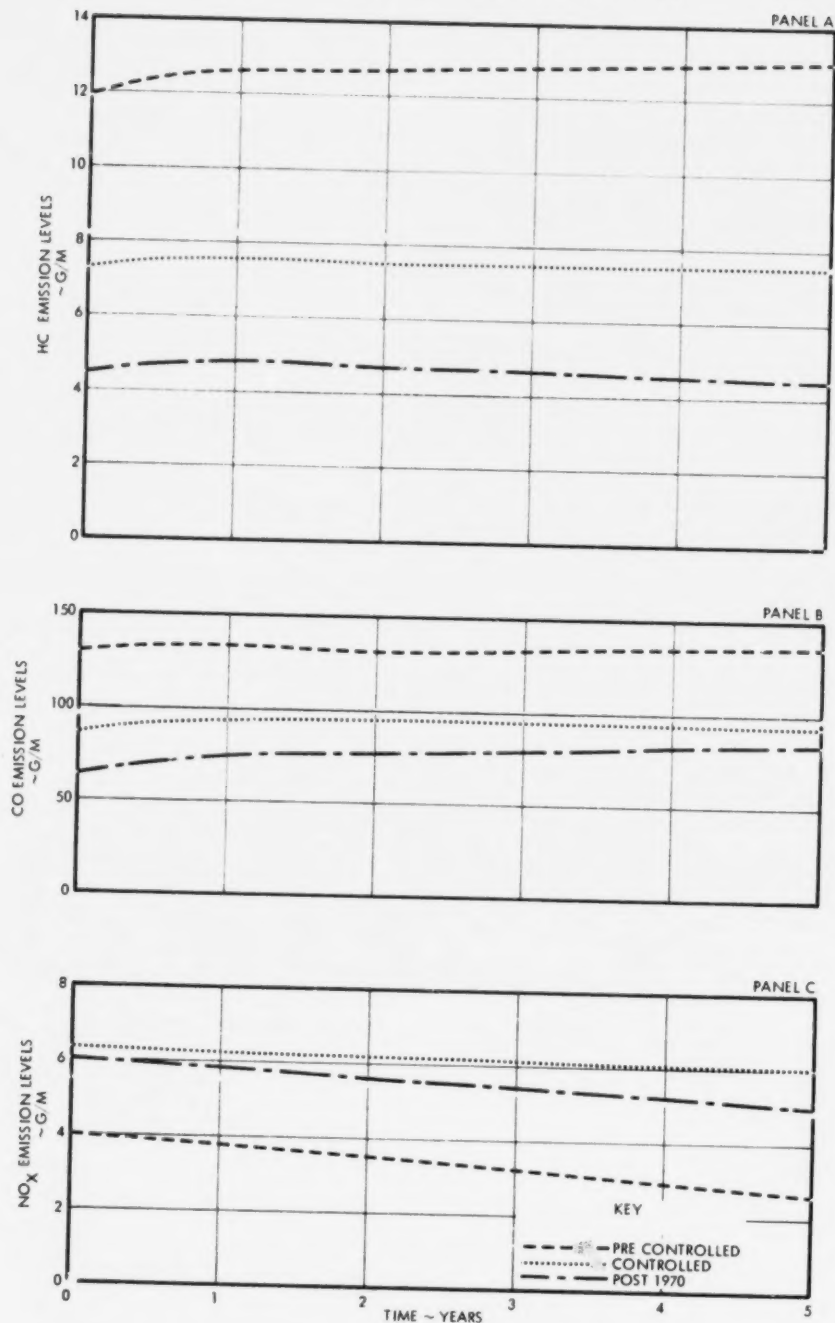


FIGURE 3-3 EMISSION TIME HISTORIES BY CONTROL FOR AN ENGINE PARAMETER INSPECTION FOLLOWED BY EXTENSIVE "B" MAINTENANCE

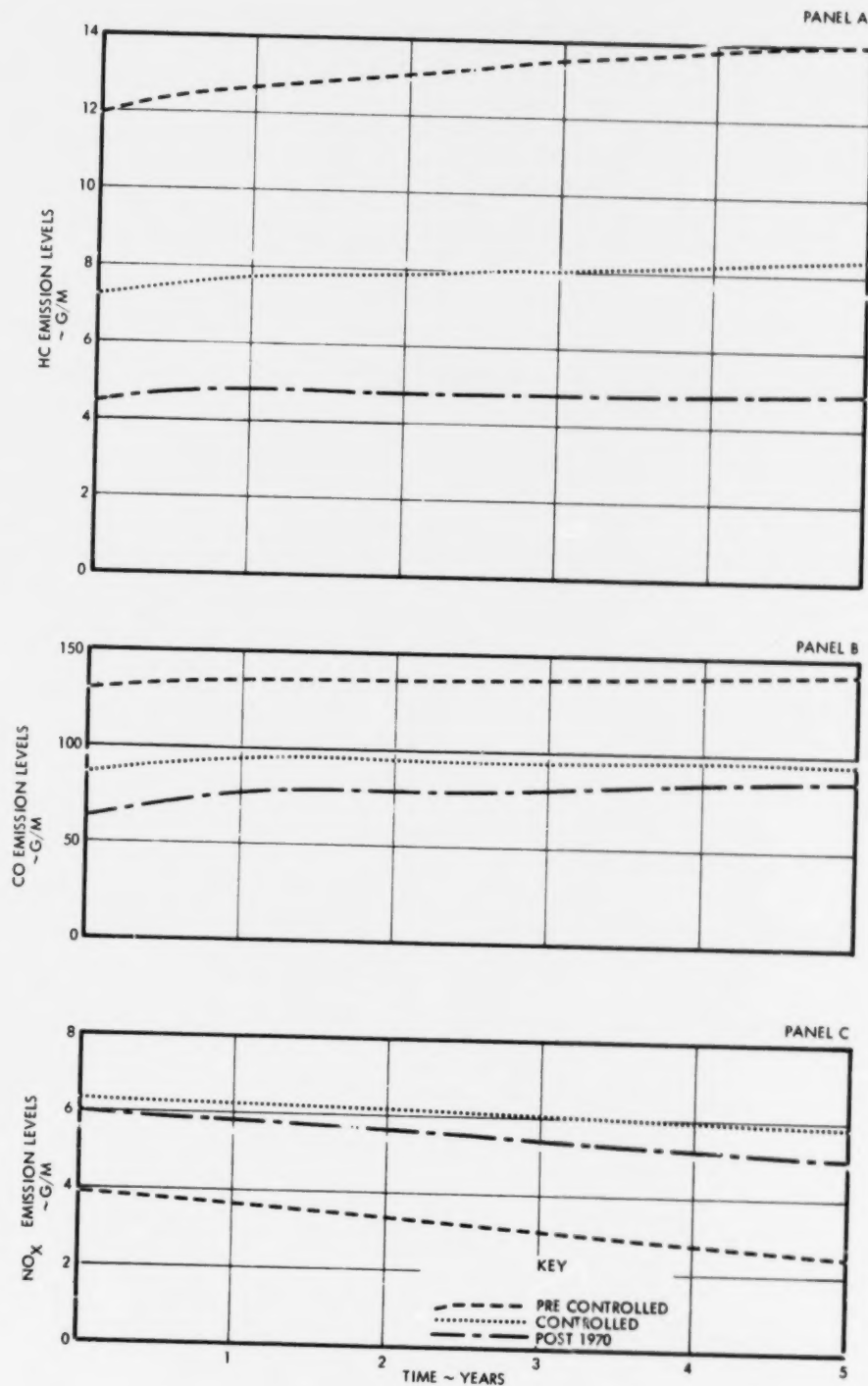


FIGURE 3-4 EMISSION TIME HISTORIES BY CONTROL TYPE FOR AN EMISSION INSPECTION FOLLOWED BY EXTENSIVE "B" MAINTENANCE

3.3 VEHICLE REJECTED FRACTION AND ENGINE PARAMETER HISTORIES

The underlying reasons, of course, for emissions changes are that engine parameter malfunctions and maladjustments are being detected and repaired. Computed values of vehicle rejection rates relative to the total population are presented in Panels A and B of Figures 3-5 for optimized procedures involving the two basic inspection approaches. The failure rates reported herein are larger than those presented in the Interim Report and are the direct result of ineffective maintenance. Minimum emission reduction goals were achieved in the study described in the Interim Report using lower vehicle rejection rates since the emission reduction produced by maintenance were larger because of perfect maintenance.

The impact of maintenance effectiveness on rejection fraction is illustrated with the following equation:

$$\Delta e_{ij} = \left(\frac{\partial e_{ij}}{\partial P_i} \right) \cdot \Delta P_i \cdot P(P_i) \cdot \epsilon_i \quad (3-2)$$

where:

Δe_{ij} = emission reduction achieved for the j th species by adjusting the i th parameter.

$\left(\frac{\partial e_{ij}}{\partial P_i} \right)$ = influence coefficient for the j th emission with respect to i th parameter

ΔP_i = average adjustment of the i th parameter performed on rejected vehicles

$P(P_i)$ = failure probability for i th parameter

ϵ_i = maintenance effectiveness for i th parameter

Typical CO emission reductions with respect to idle CO are presented below:

$$\Delta e_{CO} = (11.5) \cdot (2.4) \cdot (.65) \cdot (.60) = 10.76 \text{ g/mi} \quad (3-3)$$

$$\Delta e_{CO} = (11.5) \cdot (2.4) \cdot (1.00) \cdot (.39) = 10.76 \text{ g/mi} \quad (3-4)$$

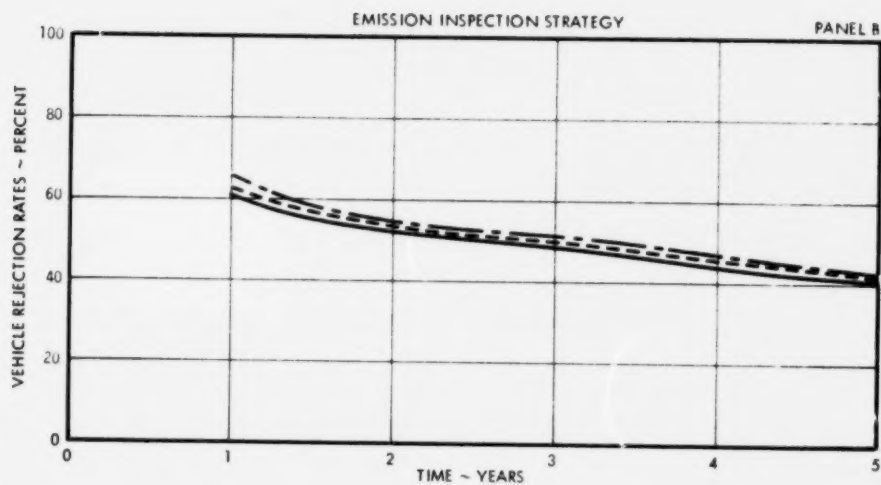
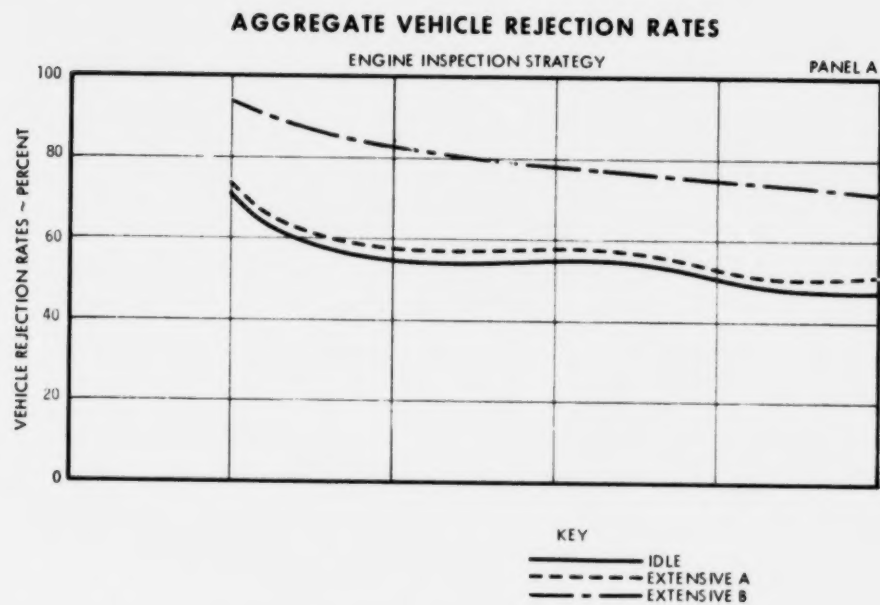


FIGURE 3-5 VEHICLE POPULATION REJECTION RATES FOR ENGINE AND EMISSION INSPECTION STRATEGIES

Equation 3-3 shows the expected CO emission reduction achieved by maintaining idle CO with a vehicle rejection fraction of 0.65 and a maintenance effectiveness of 60 percent. The same reduction (10.76 g/mi) can be achieved, equation 3-4, by failing only 39 percent of the vehicle population when perfect maintenance effectiveness is assumed. It has been assumed in this example that ΔP_i remains constant regardless of the vehicle rejection rate. In actuality its value increases as the probability of failure decreases. Consequently, the failure rate for the second example will be even lower than the 39 percent reported.

It is significant to note that the vehicle rejection fractions are relatively insensitive to inspection procedure and degree of maintenance. The exception is the parameter inspection and maintenance procedure which includes treatment of the induction subsystem (extensive "B" maintenance). Insensitivity to inspection and maintenance procedure results from two counteracting effects. Emission signature inspections result in errors of commission by rejecting vehicles which do not contain malfunctions. By definition, the direct inspection of maladjustments and malfunctions does not make this type of error. Hence, for similar rejection fractions parameter inspection procedures should be more effective. The opposing influence results from the optimization itself. For example, the addition of misfire detection and correction to an idle adjustment program requires that fewer vehicles with advanced timing maladjustments be rejected in order to achieve a specific emission reduction goal.

The significant difference in rejected fractions for the engine parameter inspection and the extensive "B" maintenance results from detecting malfunctions in the large number of components of the induction subsystem which have a fairly high failure frequency. The emission signature inspections by comparison find only between zero and 40 percent of these failures.

At the first inspection interval, the state of vehicle maintenance varies widely resulting in high initial rejection fractions. Values range between 60 to 90 percent of the vehicle population. At subsequent inspection intervals engine parameters in the population are under better control and the vehicle rejection fraction decreases.

Figure 3-6 shows the engine parameter rejection rate time histories for the nine parameter considered in the 1966-70 controlled vehicle fleet as well as for NO_x control for the post 1970 vehicle fleet. Very little decrease in rejection fraction with time is found for some of the engine parameters while a substantial shift is found for timing and air cleaner restriction. This sensitivity of the rejection fraction to individual engine parameters relates directly to the degree to which they are out-of-specification at program initiation, to their deterioration rates, and the effectiveness of maintenance. For example, a large percentage of vehicles have timing maladjustments most of which are corrected during the first inspection/maintenance cycle. Since timing adjustments deteriorate slowly subsequent inspections with a fixed pass/fail level find fewer malfunctions of this type. Over five years, the rejection fraction for timing was found to drop from 50 percent to less than 10 percent. For the more highly leveraged but infrequent malfunctions such as misfire, air pump failure, and NO_x control component malfunctions, a slowly decreasing rejection fraction occurs over the five-year program period.

A third characteristic deterioration profile is typified by a rapid decrease in rejection rate for several years followed by restabilization at about 50 percent of the initial value. A number of induction system parameters (PCV, idle speed, choke blade setting and heat riser) follow this trend.

Since the total vehicle rejection fraction is estimated from these elements, it tends to have a shape similar to the most frequently occurring profiles having high rejection fractions. As noted in Volume III, the vehicle rejection fractions are estimated with a statistical model which assumes a random distribution of malfunctions throughout the vehicle population. Therefore, the trend in total vehicle rejection rates follows that of idle fuel to air and rpm for idle adjustment maintenance, and additionally PCV, and the choke parameters when induction subsystem maintenance is considered. Because ignition system components have low failures rates, they do not have a substantial effect on vehicle rejection rates.

ENGINE PARAMETER REJECTION RATES (CONTROL FLEET)

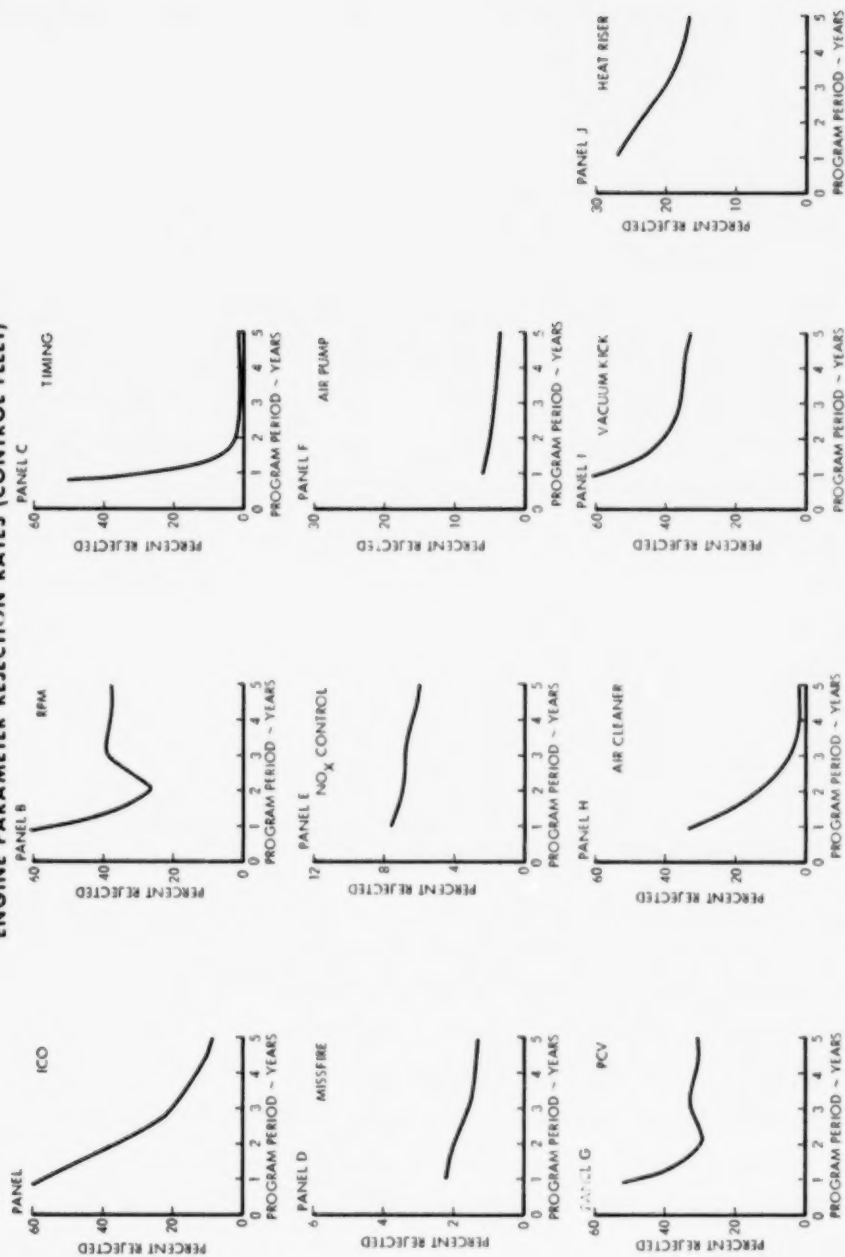


FIGURE 3-6 ENGINE PARAMETER REJECTION TIME HISTORIES FOR AN EXTENSIVE B MAINTENANCE TREATMENT (1966-1970 CONTROL TYPE WITH POST 1970 NO_x CONTROL)

AGGREGATED MODE EMISSION REJECTION RATES

AGGREGATE POPULATION

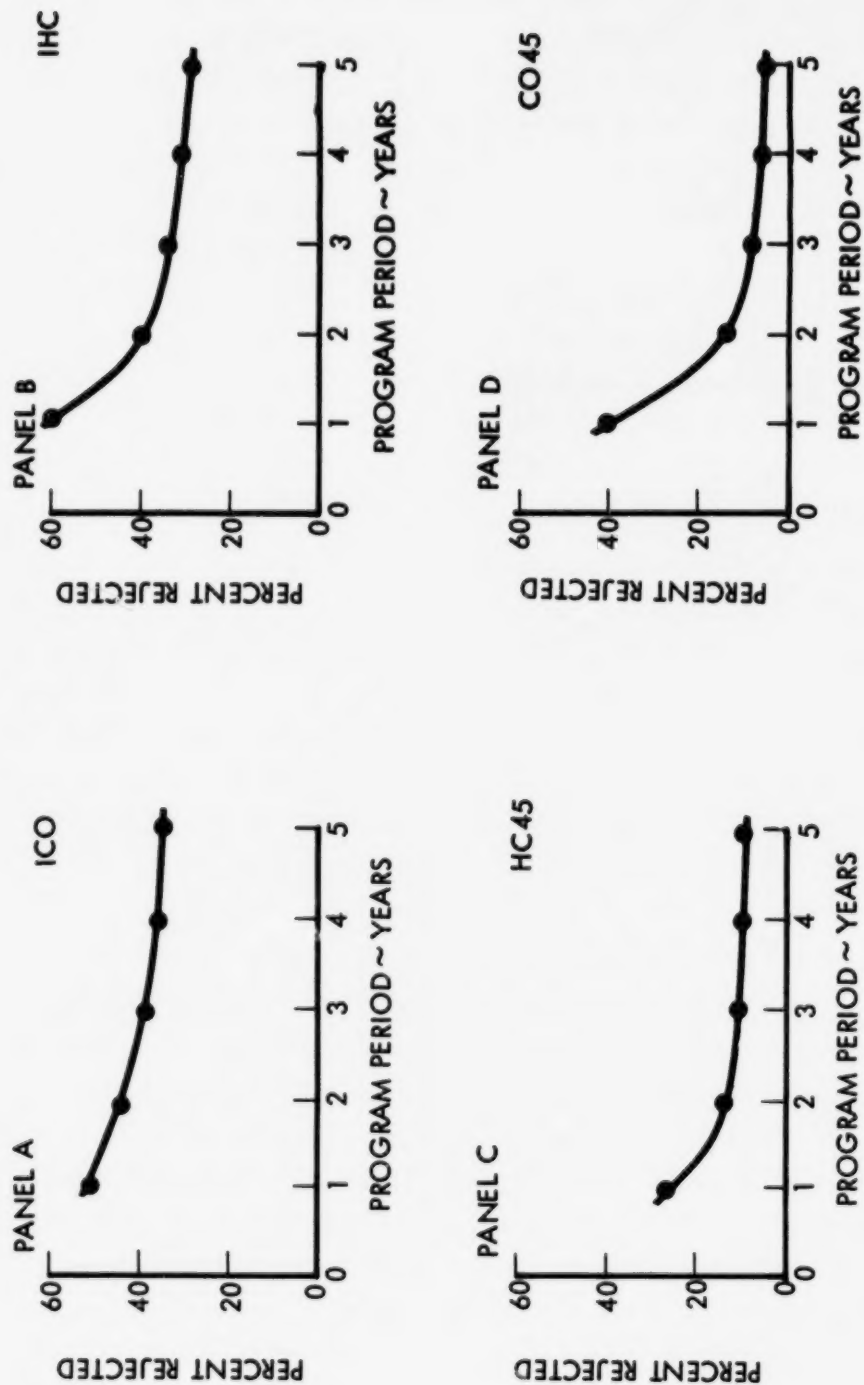


FIGURE 3-7 MODE EMISSION REJECTION TIME HISTORIES FOR AN EXTENSIVE B MAINTENANCE TREATMENT

Figure 3-7 presents the population weighted fraction of vehicles rejected in an emission inspection by each separate idle or loaded mode measurement of CO and HC. As can be seen, the rejected fractions based upon idle CO measurements are relatively insensitive to program duration. This is because this mode is most sensitive to the idle fuel-to-air adjustment which deteriorates rapidly and not to the induction system malfunctions which have a longer deterioration profile. Although CO emissions measured under load identify only 10 to 40 percent of the induction system malfunctions of interest, sufficient failures are found and corrected in the first year to reduce 45 mph CO emission levels and, hence, rejection fractions in latter years.

Inspections using both idle and loaded mode HC emission levels result in a vehicle rejection level which decreases sharply with inspection program duration. This is because the first inspection finds most of the misfires within the general population with few errors of omission being committed. The remaining parameters effecting HC emissions (NO_x control and timing) are infrequently malfunctioned and maladjusted, have low deterioration rates, and/or are not adequately diagnosed with this procedure. Indeed, the effectiveness of the emission inspection strategy can largely be attributed to the adequate diagnosis of idle fuel-to-air ratio maladjustment and misfire.

3.4 OPTIMIZED MAINTENANCE PROCEDURES

The engine parameters and mode emissions selected for use in a mandatory vehicle inspection and maintenance program by the Economic Effectiveness Model and the inspection failure criteria for each are summarized in Table 3-3. The engine parameter pass/fail criteria are given relative to their specification or nominal values. The engine parameters selected by the model are idle CO, misfire, PCV valve and air cleaner for all three vehicle fleets. For controlled vehicles prior to 1971 the idle adjustments of rpm and timing are also cost-effective to maintain. It is again emphasized that this selection is based upon minimizing a figure of merit which incorporates specific weight factors on emission reductions. A different figure of merit incorporating other emissions weighting factors may result

TABLE 3-3 OPTIMAL PASS/FAIL CRITERIA
FOR LOS ANGELES

PARAMETERS/MODE EMISSIONS	OPTIMAL SYSTEM PASS/FAIL CRITERIA*					
	PRECONTROLLED		CONTROLLED		POST 1970	
	PARAMETER DELTA	MODE EMISSION	PARAMETER DELTA	MODE EMISSION	PARAMETER DELTA	MODE EMISSION
o IDLE						
o IDLE CO (%)	0.05	5.9	0.05	3.8	0.04	3.2
o RPM	----	--	5.00	250.0	----	--
o IDLE HC (PPM)	----		0.05		----	
o TIMING (DEG)						
o IGNITION						
o MISFIRE (%)	2.50	450.0	2.50	250.0	2.50	200.0
o NO _x	---		---		---	
o INDUCTION						
o AIR PUMP	---		----		---	
o PCV (CFPM)	-0.02		-0.03		-0.01	
o AIR CLEANER (DEG)	30.00	3.5	25.00	1.5	10.00	1.0
o CHOKE VACUUM KICK (IN.)	----		----		----	
o CHOKE HEAT RISER	----		----		----	

Key: ____ Vehicle not equipped

---- Parameter not inspected

-- Mode emission not inspected

* As measured from manufacturers spec.

in selecting other procedures. Generally, a specific engine parameter will be discarded for one or several of the following reasons:

- Its repair results in an increase of one of the emissions
- Its inspection and/or repair costs are large relative to the emission reduction effected
- The engine parameter or its influence is unique to only a small subset of the vehicle population.

In the first category are parameters related to ignition spark timing which tend to have counter productive effects. Upon retarding the ignition timing the CO emissions increase 10 times faster than the HC and NO_x emissions decrease.

The choke system (vacuum kick and heat riser valve) fall generally into the second category of low leveraged repairs. Although these parameters have large influence coefficients for CO emissions and are frequently failed their repair costs are high and maintenance effectiveness low. The importance of maintaining these parameters in a mandatory program of inspection and maintenance is also reduced when a low weighting factor is assigned to CO emission reductions.

The NO_x control device and air reactor systems are typical of the third category in that only a small fraction of the vehicle population are equipped with these control systems. Further the failure rates of these control systems are low.

For each engine parameter selected, the analytical procedure tended to place the pass/fail criterion near the mode of its population distribution or near manufacturer's specification (e.g., 50 percent rejection rates were often typical). Only in this way could maximum cost effectiveness be achieved together with the stated program emission reduction goals.

The influence of deleting and/or reintroducing the least effective engine parameters into the analysis was briefly studied for the extensive maintenance procedures. Table 3-4 contrasts the extensive "A" maintenance with and without NO_x control system repair (cases 1 and 2). The increased CO emission resulted in a figure of merit which was 10 percent higher than the procedure which did not include inspection and maintenance of the NO_x control device.

A number of variations were also studied for the extensive "B" treatment. Cases four, five and six show the effect on system performance as the choke, NO_x control and air pump subsystems are added to the inspection and maintenance process. The resultant figures of merit improve as these parameters are omitted from the procedure. Again, this can be attributed in large part to ineffective maintenance of induction system failures.

In addition to maintenance effectiveness and parameter deterioration rates the singularly most significant factor influencing procedure effectiveness was the shift in vehicle population characteristics. Table 3-5 reveals the compositional makeup of the three vehicle fleets for the first five years of operation. While the average odometer readings for the total fleet remain about the same for each year the percentage composition for the new cars increases dramatically. These population characteristics reflect a vehicle population growth from 4 million to 4.6 million over five years (an average growth rate of 3 percent per year). The substantially lower mileage accumulation rates for the 1966 vehicles along with their smaller percentage of the total population in latter years indicates the marginal utility of including these vehicles in an inspection and maintenance program.

TABLE 3-4 COMPARISON OF EXTENSIVE MAINTENANCE PROCEDURE VARIATIONS

INSPECTION/MAINTENANCE PROCEDURES	FIGURE OF MERIT \$/TON+			COST PER VEHICLE		EMISSION REDUCTIONS, PERCENT			
	A	B	C	D	E	HC	CO	NO	
ENGINE PARAMETER INSPECTION									
1. EXTENSIVE A ⁺⁺	1950	735	1120	18.00	24.50	10.8	2.5	-0.1	
2. EXTENSIVE A WITHOUT NO _x CONTROL	1780	645	1020	16.30	22.40	10.8	2.6	-0.2	
3. EXTENSIVE B ⁺⁺⁺	2235	795	1200	28.75	33.10	11.7	5.2	-1.0	
4. EXTENSIVE B WITH VACUUM CHOKE KICK	2480	900	1380	32.00	34.85	11.7	5.2	-1.0	
5. EXTENSIVE B WITHOUT NO _x CONTROL & AIR PUMP	1990	700	1070	25.40	29.50	11.6	5.3	-1.1	
6. EXTENSIVE B WITHOUT NO _x CONTROL, AIR PUMP, AND HEAT RISER	1975	695	1070	24.80	29.20	11.6	5.1	-1.1	

+ L.A. BASIN WEIGHTING FUNCTION

++ IDLE PLUS IGNITION DYNAMOMETER

+++ IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

A. Computed over five year period.

B. Computed at end of last interval.

C. Based on statistically significant emissions reductions for last interval.

D. Based on total vehicle population.

E. Based on maintained portion of vehicle population.

TABLE 3-5 VEHICLE POPULATION CHARACTERISTICS

YEAR	VEHICLE DISTRIBUTION PERCENT	INCREMENTAL READING MILES	HC	VEHICLE EMISSION CO GRAMS/MILE	LEVELS NO	VEHICLE POPULATION
1	PRECONTROLLED	4157	11.94	129.80	3.97	
	CONTROLLED (1966-1970)	8418	7.26	86.60	6.34	
	POST 1970	14014	4.43	63.40	6.00	
	TOTALS	8225	8.18	95.70	5.50	4000000
2	PRECONTROLLED	3908	12.58	133.05	3.74	
	CONTROLLED (1966-1970)	7262	7.54	93.69	6.27	
	POST 1970	13022	4.78	74.59	5.84	
	TOTALS	8281	7.89	97.23	5.51	4120000
3	PRECONTROLLED	3735	12.63	131.39	3.55	
	CONTROLLED (1966-1970)	6265	7.45	93.84	6.19	
	POST 1970	12192	4.69	75.96	5.63	
	TOTALS	8312	7.22	93.07	5.48	4243600
4	PRECONTROLLED	3562	12.76	133.27	3.25	
	CONTROLLED (1966-1970)	5409	7.48	94.46	6.12	
	POST 1970	11471	4.64	79.11	5.40	
	TOTALS	8328	6.69	91.57	5.36	4370908
5	PRECONTROLLED	3403	12.89	135.08	2.94	
	CONTROLLED (1966-1970)	4743	7.49	94.51	6.05	
	POST 1970	10783	4.56	81.64	5.18	
	TOTALS	9335	6.21	90.51	5.21	4502035
6	PRECONTROLLED	3268	13.00	136.72	2.64	
	CONTROLLED (1966-1970)	4441	7.50	93.83	5.98	
	POST 1970	10108	4.47	83.38	4.97	
	TOTALS	8336	5.76	89.54	5.03	4637096

4.0 SYSTEM SENSITIVITY ANALYSIS

The preliminary nature of the first year's experimental data raised a number of questions concerning the accuracy of predicted emission reductions. In an attempt to address these issues, the Economic Effectiveness Model was used to determine the sensitivity of model generated results to changes in the basic data set. Furthermore, the model was employed to measure the impact of various operational variables, e.g., inspection period and cost elements, on overall system performance.

The major system variables considered in the sensitivity study were:

- garage maintenance effectiveness
- engine parameter deterioration rates
- emission deterioration rates
- levels of voluntary maintenance
- emission weighting factors (figure of merit)

Each of these variables represents an important aspect of the overall inspection/maintenance process. Garage maintenance effectiveness specifies the extent to which the various engine parameters are properly maintained. The deterioration rates determine the engine parameter changed with time. Correspondingly, emission deterioration rates are calculated directly based upon the deterioration of engine parameter settings and give the change in vehicular emission levels as a function of time. All three of the aforementioned data sets were derived directly from the emission test program described in Volumes IV and V. The emission influence coefficients, although of primary importance, were not considered in this sensitivity analysis because their values were known with higher reliability.

Estimates for the extent of voluntary maintenance and values for the emission weighting factors were made outside the test program. In the case of voluntary maintenance, however, the California Air Resources Board emission surveillance data set was used in estimating the actual levels and extent of the voluntary program. Sections 4.1 through 4.5 assess the implications of variations in these estimates on procedure effectiveness.

The two operational variables of most concern are frequency of inspection and the inspection pass/fail criteria. Each of these variables can significantly affect the performance of the various strategies. Both of these variables are examined in detail in Section 4.5.

Whereas the accuracy of the cost data is verifiable, the implications of variations in program costs are of utmost importance. This is especially the case for tradeoffs between the state lane and franchised garage procedures. Section 4.7 reveals the impact of selected cost variations on system performance.

Two reference cases were used in conducting these sensitivity studies. These are an Engine Parameter Inspection and an Emission Signature Inspection each coupled with an extensive "B" maintenance treatment. The impact of changes in the basic emission data set on system performance were contrasted directly against this reference. This resulted in a quantitative estimate on the sensitivity of each data set. The use of the two references allowed for both intra and inter strategy comparisons.

4.1 SERVICE ORGANIZATION MAINTENANCE PERFORMANCE

One emission related variable that has a dramatic effect on potential emission reductions is the effectiveness of maintenance by various classes of service organizations. Table 4-1 shows a comparison between the performance results derived using both the actual experimentally determined maintenance effectiveness (Volume IV) and perfect maintenance ($\eta=100\%$). This table shows that an increase in maintenance effectiveness results in a substantial improvement in both the figure of merit and emission reductions. This is especially true for CO where a threefold increase in emission reduction was realized for the extensive "B" procedure.

This result can be traced to the relative low maintenance effectiveness observed for the engine parameters having a large effect on CO emissions, e.g. idle CO, air pump and choke system. The effectiveness for the CO related parameters averages about 60 percent as compared to a nearly 90 percent average for hydrocarbon related parameters of engine RPM and timing. Comparison of results for the two basic inspection strategies is also interesting. The greatest improvement in program performance is

TABLE 4-1 THE IMPACT OF MAINTENANCE EFFICIENCY
ON PROCEDURE EFFECTIVENESS

INSPECTION/MAINTENANCE PROCEDURES	FIGURE OF MERIT \$/TON+++		EMISSION REDUCTIONS, PERCENT					
			HC		CO		NO	
	A	T	A	T	A	T	A	T
ENGINE PARAMETER INSPECTION								
1. IDLE (FRANCHISED)	950	285	2.4	3.8	2.6	10.7	-0.2	-0.5
2. EXTENSIVE A+ (FRANCHISED)	1950	885	10.8	14.2	2.5	10.2	-0.1	0.4
3. EXTENSIVE B++ (FRANCHISED)	2235	1095	11.6	15.7	5.3	14.6	-1.1	-1.2
EXHAUST EMISSION INSPECTION								
4. IDLE (STATE LANE)	730	215	1.5	2.8	2.9	11.2	-0.0	-0.4
5. EXTENSIVE A+ (STATE LANE)	1305	545	7.9	10.3	2.9	11.2	-0.0	-0.4
6. EXTENSIVE B++ (STATE LANE)	1475	635	8.1	10.6	3.4	11.9	-0.3	-0.8

+ IDLE PLUS IGNITION TUNEUP WITH DYNAMOMETER

++ IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

+++ L.A. BASIN WEIGHTING FUNCTION (AVERAGE OVER FIVE YEARS)

A: ACTUAL MAINTENANCE PERFORMANCE (VOLUME V)

T: PERFECT MAINTENANCE PERFORMANCE
($\eta = 100\%$)

achieved in the two idle programs. Differences in figure of merit values for these two programs also narrow as a result of improved maintenance. This can be attributed to the potentially higher emission reductions that can be achieved using a direct engine parameter inspection. The emission reductions achieved with perfect maintenance are consistent with those reported in the interim report for similar strategies. The slightly higher percentage CO emission reductions reflect the larger influence coefficient for idle CO adjustment for post 1970 vehicles.

It is significant to note that the rank order of the various strategies by their economic effectiveness does not change with improved maintenance. An idle emission inspection followed by idle adjustment is still the most cost effective program although only small reduction of HC emissions are achieved. The practicability of this procedure however is significantly enhanced because of the substantial CO emissions reductions effected.

It becomes clear that a program designed to improve the maintenance effectiveness of service organizations will have a large effect on the viability of mandatory vehicle inspection and maintenance for reducing exhaust emissions. A study of methods for improving maintenance effectiveness and a pilot training program should be undertaken prior to the implementation of statewide inspection/maintenance programs.

4.2 ENGINE PARAMETER DETERIORATION RATES

The influence of uncertainty in parameter deterioration rates was also studied. Figure 4-1 shows the sensitivity of the figure of merit (Panel A) and emission reductions (Panels B, C and D) to varying all parameter deterioration rates are by $\pm 30\%$. Values for the figure of merit are based on the L.A. Basin weighting factors and are determined for the two basic inspection strategies each followed by extensive "B" maintenance. These results show the importance of parameter deterioration on overall program effectiveness. For high rates of deterioration, the program is substantially more cost effective than for lower rates. The convergence in figures of merit between the two inspection approaches is due to the higher reliability of the direct engine parameter inspection. In terms of specific parameters, program performance appears most sensitivity to misfire for HC emission reductions and idle CO for CO emission reductions.

INFLUENCE OF PARAMETER DETERIORATION EXTENSIVE B MAINTENANCE

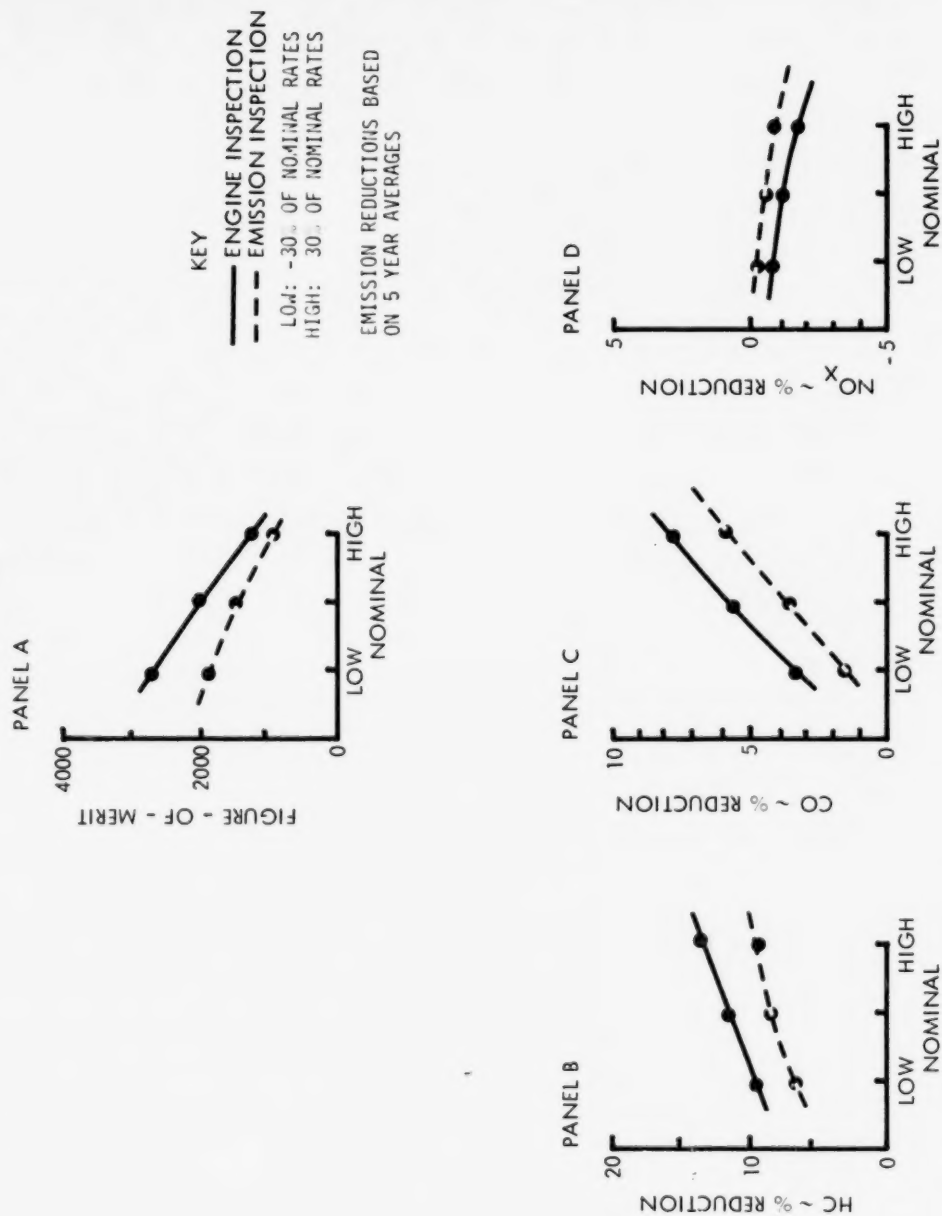


FIGURE 4-1 INFLUENCE OF PARAMETER DETERIORATION
RATES ON PROCEDURE EFFECTIVENESS FOR EXTENSIVE
"B" MAINTENANCE TREATMENT

4.3 EMISSION DETERIORATION

The emission deterioration data represent the third area where experimental results are used directly in the model. In this case, however, only that portion of the measured rates not accounted for by engine parameter adjustment deterioration is required in the simulation process. The remaining segment can be developed from the basic influence coefficients and parameter deterioration data as shown below.

$$\begin{aligned} \text{Total emission} &= \sum (\text{Influence}) \quad \times \quad (\text{Parameter}) \\ \text{deterioration} & \quad (\text{coefficients}) \quad (\text{deterioration}) \\ \text{for each} & \quad \quad \quad (\text{rates}) \\ \text{emission} & \\ \text{species} & + E_0 \text{ (Emission deterioration not} \\ & \quad \quad \quad \text{accounted for by the ten engine} \\ & \quad \quad \quad \text{parameters)} \end{aligned}$$

E_0 can be determined by simply subtracting the summed product of the influence coefficients and parameter deterioration rates from the total emission deterioration values. Obviously, the more emission deterioration accounted for by the ten parameter system the smaller the value for E_0 . Estimates for E_0 were made based on a synthesis of the ARB and TRW experimental data. Computed values for E_0 averaged approximately ten percent of total emission deterioration for all three emission species.

Figure 4-2 presents the results of a sensitivity analysis on E_0 . Shown are emission time histories for HC, CO and NO_x based on nominal and $\pm 100\%$ of nominal values of E_0 . The low E_0 case indicates that essentially all emission deterioration can be accounted for by the ten parameters, whereas, the high E_0 settings implies that only about 80 percent is due to observed parameter deterioration.

The differences predicted for high and low values of E_0 appear small when compared to the absolute emission levels. This is primarily attributed to the relatively small contribution of E_0 to the total emission deterioration rate.

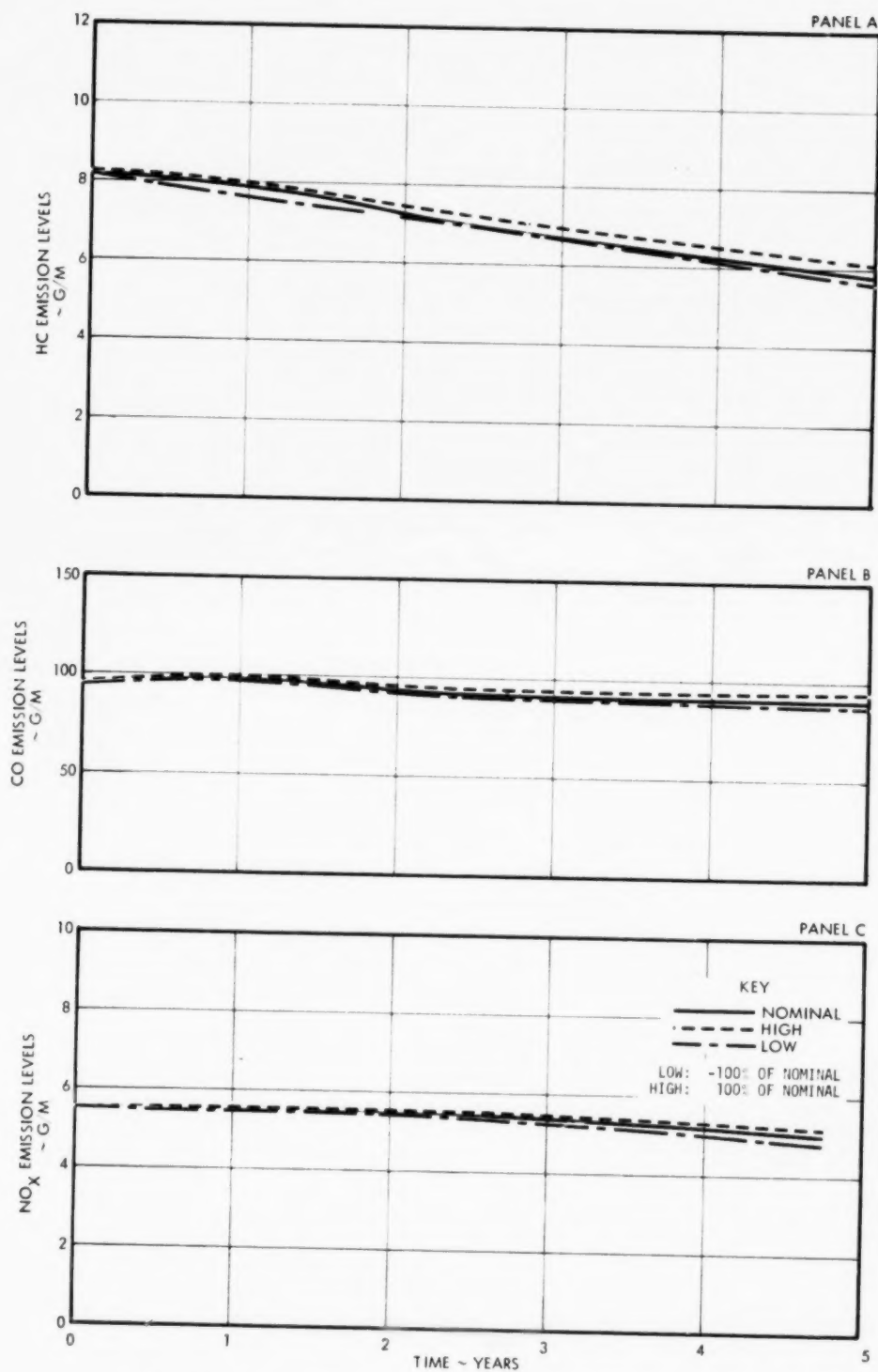


FIGURE 4-2 INFLUENCE OF EMISSION DETERIORATION ON PROCEDURE EFFECTIVENESS

4.4 VOLUNTARY MAINTENANCE EFFECTIVENESS

The impact of voluntary maintenance on a program of effectiveness can be substantial. Since specific experiments were not conducted to characterize this effect, a model for determining the influence of voluntary maintenance upon exhaust emissions was synthesized using available data elements and verified against existing vehicle emissions surveillance data. An estimated one year period between voluntary tune-ups was used and the extent of maintenance was varied in adjusting the model to fit the data. Because of modeling uncertainty it became important to assess the influence of various levels of voluntary maintenance on procedure effectiveness.

Figure 4-3 shows the impact of changes in voluntary maintenance on the program figure of merit and associated emission reductions. The extent of voluntary maintenance of individual engine parameters was varied by ± 20 percent. As expected, a less effective voluntary maintenance program results in a more attractive mandatory program as indicated by the reduced figure of merit. CO emission reduction is shown to be extremely sensitive to the extent of mandatory maintenance. Improving the reliability and extent of a voluntary program may be a viable alternative to a mandatory inspection maintenance program and could be highly attractive in terms of its cost effectiveness.

INFLUENCE OF VOLUNTARY MAINTENANCE

EXTENSIVE B MAINTENANCE

KEY
 LOW: - 20% OF NOMINAL EXTENT
 HIGH: + 20% OF NOMINAL EXTENT
 EMISSION REDUCTIONS BASED
 ON 5 YEAR AVERAGES

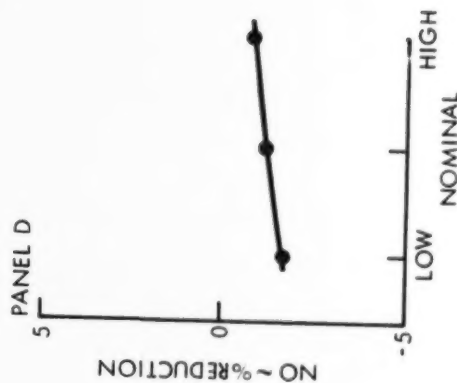
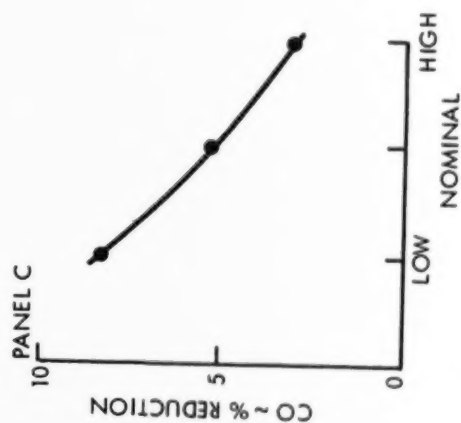
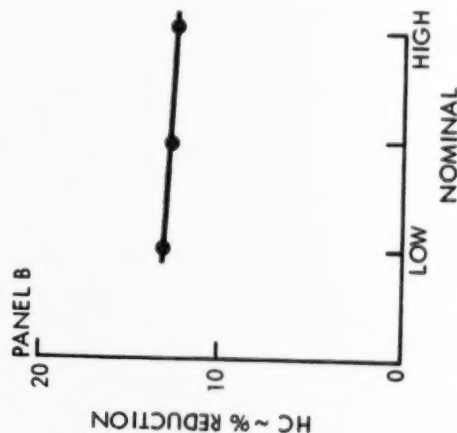
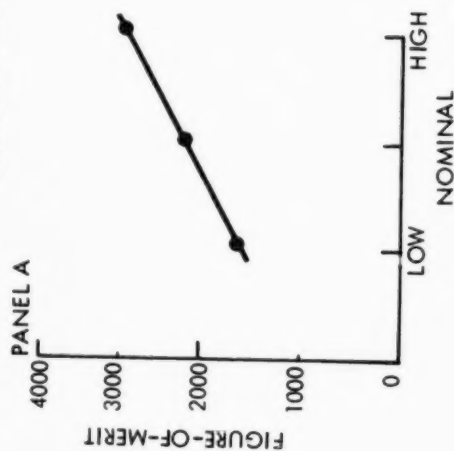


FIGURE 4-3 INFLUENCE OF VOLUNTARY MAINTENANCE ON PROCEDURE EFFECTIVENESS

4.5 EMISSION WEIGHT FACTORS

Problems associated with defining a relevant and consistent figure of merit for a program of vehicle inspection/maintenance is discussed at some length in Volume III. A major factor in the selection of optimal procedures is the importance assigned to the reduction of various emission species. The weighting factors of 0.6, 0.1 and 0.3 applied to HC, CO and NO_x reductions, respectively, represent an assessment of the importance of each type of emission on health and other emissions effects in the Los Angeles Basin. Changing the weighting factors produces substantial shifts in the relative effectiveness of candidate procedures.

Table 4-2 presents some typical economic effectiveness results for three different sets of emission weighting factors. Case 1 involves the weighting factors just discussed which typify regions with a photochemical smog problem. Case 2 emphasizes the importance of HC emissions reductions whereas, Case 3 focuses on reducing CO emissions. Both cases 2 and 3 show improved performance for all procedures when compared to Case 1. This can be attributed in part to the fairly high weighting factor given to NO_x reductions in Case 1. Presently, none of the procedures are designed specifically to reduce NO_x even though adjusting ignition timing reduces NO_x , at the expense of increasing CO. Therefore, assigning a nonzero weighting factor to NO_x reduction decreases the effectiveness of a specific program.

CO emissions account for approximately 90 percent of total mass emissions from automobiles. A small percentage reduction of CO therefore still results in large effect on the calculated figure of merit, even for low weighting factors. The change in the procedures ranking for Case 3 (engine parameter inspection) is a direct result of the high weighting given to CO reductions. The high CO weighting factor did not, however, affect the procedure ranking for the emission inspection strategy. This is due to the general ineffectiveness of detecting induction system malfunctions with loaded mode emission measurements.

TABLE 4-2 INFLUENCE OF EMISSION WEIGHTING FACTORS
ON PROCEDURE EFFECTIVENESS

INFLUENCE OF EMISSION WEIGHTING FACTORS

INSPECTION/MAINTENANCE PROCEDURES	UNADJUSTED FIGURE-OF-MERIT		
	CASE 1 (0.6, 0.1, 0.3) *	CASE 2 (0.9, 0.1, 0.)	CASE 3 (0.1, 0.9, 0.)
ENGINE PARAMETER INSPECTION			
1. IDLE (FRANCHISED)	950	815	150
2. EXTENSIVE A ⁺ (FRANCHISED)	1950	1455	645
3. EXTENSIVE B ⁺⁺ (FRANCHISED)	2240	1750	500
EXHAUST EMISSION INSPECTION			
4. IDLE (STATE LANE)	730	660	100
5. EXTENSIVE A ⁺ (STATE LANE)	1305	1015	325
6. EXTENSIVE B ⁺⁺ (STATE LANE)	1475	1155	340

+ IDLE PLUS IGNITION TUNEUP WITH DYNAMOMETER

++ IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

* EMISSION WEIGHT FACTORS (HC, CO, NO_x)

The effect of disregarding CO emissions upon the figure of merit and procedures selection was investigated using a modified extensive "A" maintenance procedure. For this purpose the weighting factors for HC, CO and NO_x were 0.7, 0 and 0.3, respectively. Idle rpm and timing were maintained on vehicles of all three control types and NO_x control devices were maintained on post 1970 vehicles. This maintenance treatment was found to be non-optimal when weighting factors for the L.A. Basin were used because adjusting rpm and timing increased CO emissions.

The figure of merit for this strategy was evaluated to be 3300 dollars per ton and the emission reductions for HC, CO and NO_x were 11 percent, zero percent and zero percent, respectively. The fundamental reason for the unattractive showing of this procedure is the result of the low overall emission reductions achieved. That is, even though hydrocarbon reductions were increased and were given a higher weighting factor, lower total weighted emission reductions were achieved.

4.6 OPERATIONAL PERFORMANCE

The pass/fail criteria and inspection frequency are the two most critical operational factors in an inspection/maintenance program. The pass/fail criteria determines the number of vehicles that will undergo maintenance. Restrictive pass/fail criteria results in higher vehicle rejection rates, which in turn produces larger emission reductions and higher costs. Inspection frequency acts in much the same way. Shorter inspection intervals result in more frequent maintenance and in higher emission reductions at corresponding larger costs. Longer periods, on the other hand, yield lower emission reductions for relatively modest costs. The basic tradeoff for both variables is to determine an optimal policy which results in acceptable emission reductions for reasonable program costs.

Figure 4-4 shows the effect on program performance (Panel A) and emission reductions (Panels B, C and D) of varying pass/fail criteria about their optimum values. Pass/fail criteria for both inspection strategies were varied in one case (low) to reject all vehicles whose parameter adjustments were above specification and in the other case to reject approximately one-half of the vehicles. While this does not demonstrate the effect of changing the pass/fail criterion for individual parameters or mode emissions, it does illustrate the overall implications of vehicle rejection rate on procedure effectiveness. As expected, the achieved emission reductions increase as the pass/fail criteria become more restrictive. These gains, however, are offset by larger program costs which makes these variations less cost effective than the optimal case. The sensitivity of emission reduction to pass/fail criteria is greater for the engine parameter inspection approach than for the emission inspection approach. This is because the maladjustments and malfunctions in the inductive system which affect CO emission can be detected with greater accuracy by an engine parameter inspection.

The results of a similar analysis of the sensitivity of inspection frequency is illustrated in Figure 4-5. Panel A reveals that an annual inspection yields the most cost effective program for both inspection strategies. Again, HC and CO emission reductions, Panels B and C,

INFLUENCE OF PASS/FAIL CRITERIA EXTENSIVE B MAINTENANCE

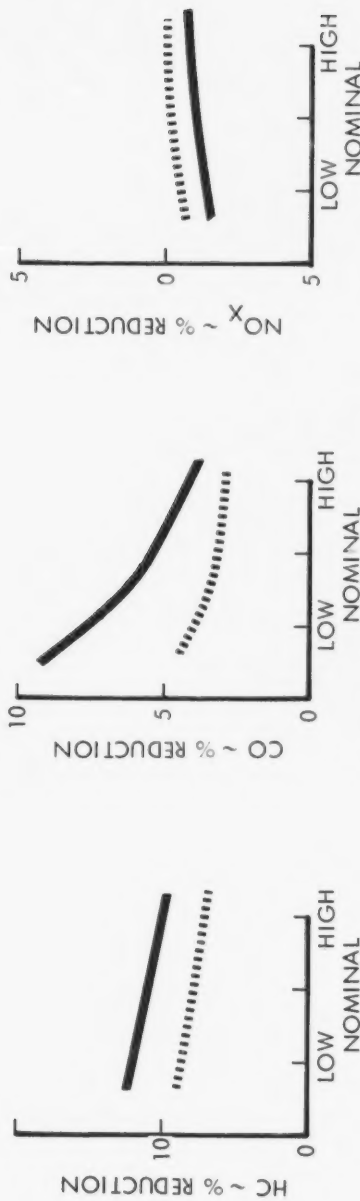


FIGURE 4-4 INFLUENCE OF PASS/FAIL CRITERIA ON
PROCEDURE EFFECTIVENESS FOR EXTENSIVE "B"
MAINTENANCE TREATMENT

increase as the time between inspections is shortened. Correspondingly, the emission reduction for these species as well as for NO_x (Panel B) tend toward zero as the frequency of inspection approaches 18 months. At this point the voluntary maintenance program becomes "equivalent" to the mandatory program and the net emission reduction (voluntary less mandatory) becomes zero. An optimum inspection frequency of 12 months is fortunate because it is consistent with current state practices relating to vehicle safety inspection and registration.

4.7 COST ANALYSIS

Labor costs constitute an important component of overall program cost. Generally speaking, a program of vehicle inspection and maintenance is labor intensive as opposed to other control approaches which may be capital intensive (e.g., fuels modification). Figure 4-6 shows the impact of changes in labor rates in franchised garages. State lane rates and user inconvenience costs (Panels A, B and C). These curves are substantially flatter than those shown in the interim report. This is the result of incorporating other costs (e.g., the cost of unnecessary maintenance) into the economic analysis which decrease the systems sensitivity to labor cost.

For an idle engine parameter inspection program, the actual cost of inspection amounts to only one-third of the total cost (the cost of unnecessary repairs constitutes one-third and information processing is about one-third). This same trend is observed with procedures involving more extensive maintenance, however, the latter two cost components tend to be relatively smaller. The result is that changes in the labor rates and user costs have a smaller effect on total program cost and consequently the program is less sensitive to changes in these values. The slight divergence in the figure of merit between the engine parameter and emission inspection strategies shown in Panel A is caused by the larger number of induction system malfunctions found by the engine parameter inspection.

INFLUENCE OF INSPECTION PERIOD

EXTENSIVE B MAINTENANCE

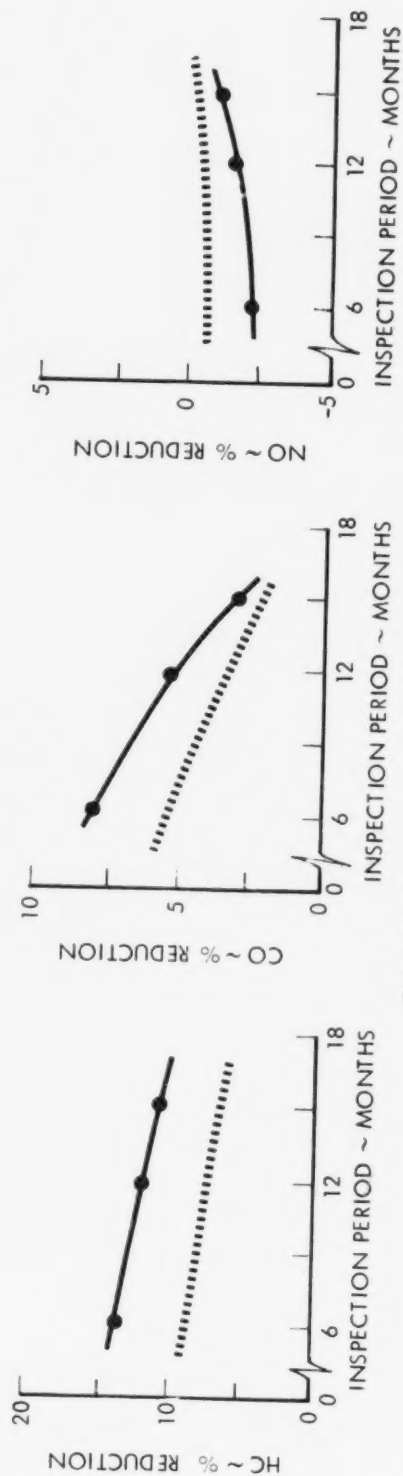
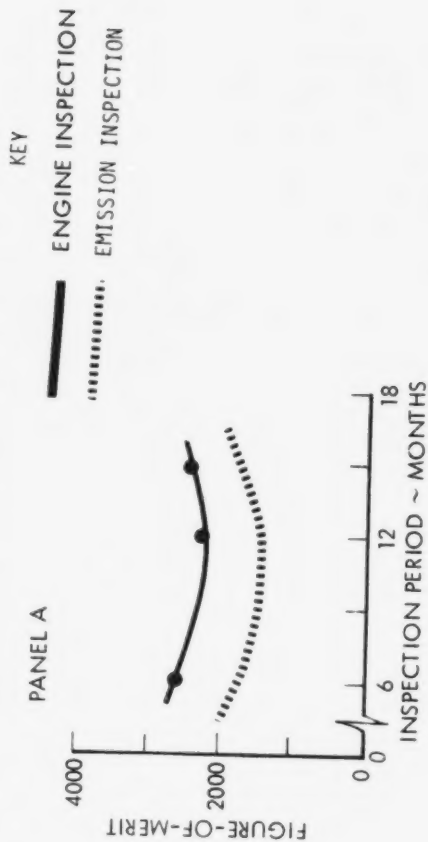


FIGURE 4-5 INFLUENCE OF INSPECTION FREQUENCY ON
PROCEDURE EFFECTIVENESS FOR EXTENSIVE "B"
MAINTENANCE TREATMENT

INFLUENCE OF PROGRAM COST COMPONENTS

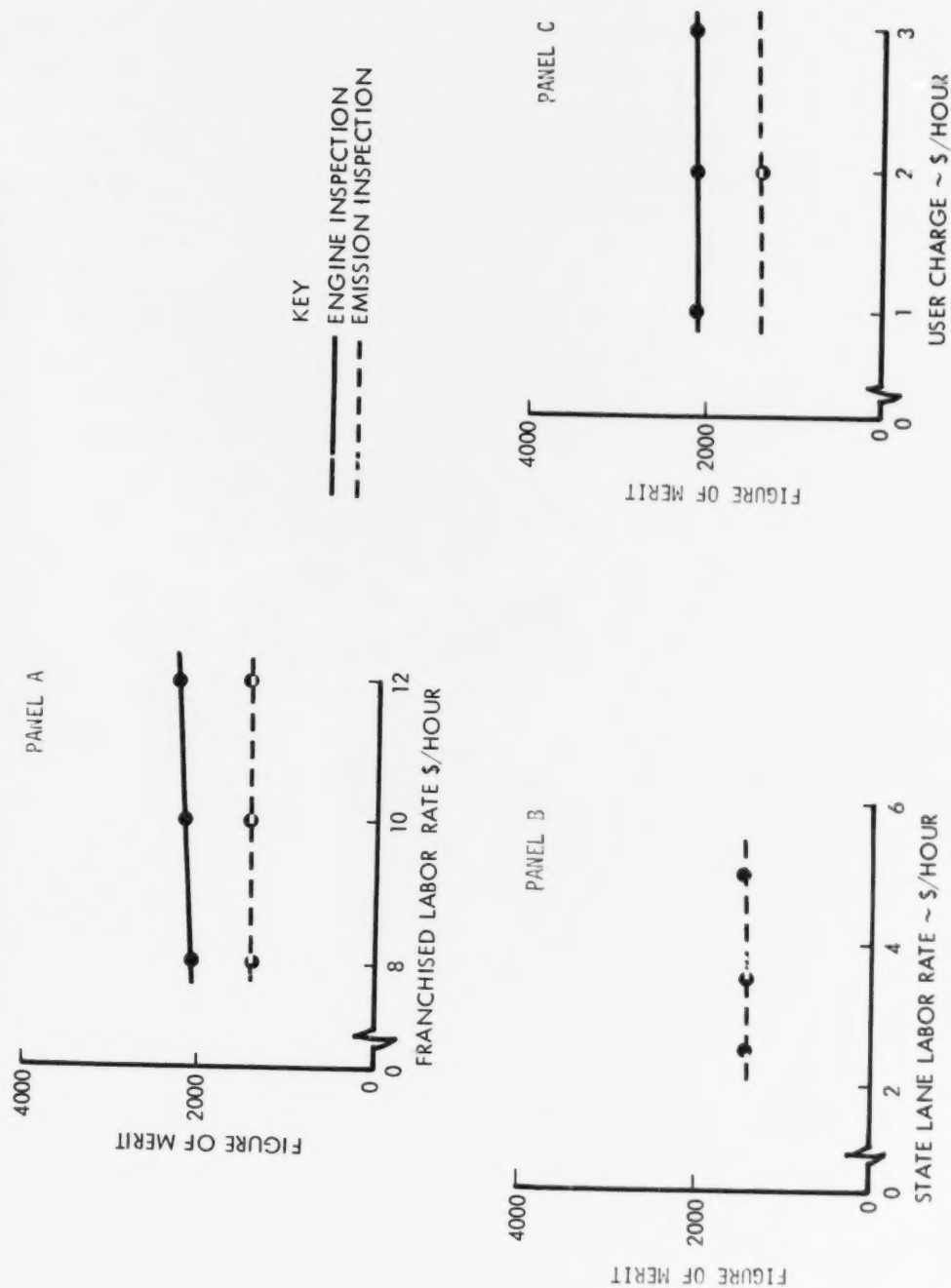


FIGURE 4-6 INFLUENCE OF PROGRAM COSTS ON PROCEDURE EFFECTIVENESS FOR EXTENSIVE "B" MAINTENANCE TREATMENTS

The owners of all vehicles including those that successfully pass an inspection are considered inconvenienced and the program is charged accordingly. Since roughly the same percentage of vehicles are being rejected by both inspection strategies the cost of user inconvenience has no impact on procedure effectiveness. The user inconvenience cost however continues to play a dominate role when selecting procedures within a given inspection strategy and for designing an optimal system configuration.

5.0 REGIONAL IMPLICATIONS OF VEHICLE INSPECTION/MAINTENANCE

While the air quality problem is national in scope, its specific characteristics vary considerably between basic geographic regions. The effectiveness of mandatory vehicle inspection/maintenance for controlling emissions therefore, must be analyzed on a regional basis. It is conceivable that a general program design could be used regardless of the air quality problem of a particular region. However, it is much more likely that particular regional characteristics will necessitate a specifically designed program to achieve maximum cost-effectiveness. From the other viewpoint, it is essential to investigate the sensitivity of an optimal program design to regional variables in order to determine the advantage of programs tailored to the needs of specific regions.

In an attempt to better understand some of these implications, an evaluation was performed using the Economic Effectiveness Model on two distinct regions of the country. Region A is characterized by a warm climate and has a photochemical smog problem that is related directly to high HC and NO_x concentrations. Region B is a cold weather area where all three exhaust emission species impact equally on the general state of the atmosphere.

Regional differences in ambient air quality were characterized in the model through the use of the emission weighting factors. The weighting factors assigned for Region A were 0.6, 0.1 and 0.3 for HC, CO and NO_x , respectively. In the case of Region B the assigned weighting factors were 0.33 for HC, 0.33 for CO and 0.33 for NO_x . The effect of these weighting factors is to force the optimal program design to maximize emission reductions for the more heavily weighted emission species.

An additional difference between these two regions was introduced in the basic characteristics of the vehicle populations. Results from the parameter adjustment surveys in Los Angeles and Detroit (Volume IV) indicated statistically significant differences in some exhaust mode emission values (primarily the CO measurements). Surveillance data

also indicate that exhaust emissions for these two areas are significantly different at the 90% confidence level except for HC emissions from pre-controlled vehicles and CO emissions for NO_x controlled vehicles. On the other hand, the engine parameter distribution data for these two regions appear to be similar. For the purpose of evaluating regional implications the following emission levels were used for characterizing the two urban centers.

TABLE 5-1 COMPARISON OF MASS EMISSION LEVELS
BETWEEN REGION A AND REGION B

Vehicle Control Type	Region A			Region B		
	HC	CO (grams per mile)	NO _x	HC	CO (grams per mile)	NO _x
Uncontrolled	11.94	129.8	3.97	10.14	89.2	2.91
Controlled	7.26	86.6	6.34	5.28	60.8	4.33
NO _x Controlled	4.43	63.4	6.00	3.36	53.4	3.73

Three control classifications were retained for both regions in carrying out the economic effectiveness analysis. The percent of vehicles falling into each category for the two regions were not the same reflecting differences in California vehicles versus those on sale in other parts of the United States.

With the exception of emission weighting factors, exhaust mode and mass emission levels, and engine parameter frequency distributors, the model assumes that the remaining vehicular attributes remain the same for both areas. These include the emission influence coefficients for main and interaction effects, parameter and emission deterioration rates, extent of voluntary maintenance and garage maintenance effectiveness. Furthermore, the analysis assumes that the basic cost elements of this program do not vary through the country.

The approach taken in assessing the impact of regional differences on procedures effectiveness consisted of:

- Designing an optimal program for each region based on the stated emissions weighting factors and other relevant data.
- Contrasting the performance characteristics of each candidate strategy between regions.

Table 5-2 contrasts the optimal regional results derived for consistent strategies. The figure of merit data for Region B appears more attractive than for Region A. In most cases this can be attributed directly to the higher weighting given CO emission reductions in Region B since the other performance measures (inspection costs and emission reductions) are nearly invariant. Although the idle program remains the most cost effective strategy, the extensive "B" maintenance treatment has now emerged in Region B as the next most attractive strategy while extensive "A" maintenance continues to be ranked second for Region A. The reversal in ranking between the extensive A and extensive B maintenance treatments for both inspection strategies reflects the high weighting given CO.

An interesting aspect of these results is that the cost per inspection computed for both regions is approximately the same for the engine parameter inspection strategy. This result is extremely interesting because the parameter set mix was not the same for the two regions. For example, in Region B (idle program) only idle air to fuel ratios were inspected and maintained for the three control groups whereas in Region A idle RPM and timing were also inspected and maintained on the 1966-70 control fleet. The idle air to fuel ratio distributions for vehicles in Region B (all control groups) differed substantially from the distributions in Region A. This resulted in slightly different idle CO pass/fail criteria for the Region B. The impact of this difference was to obtain nearly identical idle program vehicle rejection rates for the two regions which, in turn, led to the similar inspection costs per vehicle as shown in Table 5-2.

TABLE 5-2 COMPARISON OF PROCEDURE EFFECTIVENESS FOR
REGION A AND REGION B

INSPECTION/MAINTENANCE PROCEDURES	FIGURE OF MERIT \$/TON+++		COST PER VEHICLE++++		EMISSION REDUCTIONS, PERCENT					
	Region A	Region B	Region A	Region B	HC		CO		NO	
					Region A	Region B	Region A	Region B	Region A	Region B
ENGINE PARAMETER INSPECTION										
1. IDLE (FRANCHISED)	950	510	4.00	4.00	2.4	0.8	2.6	2.6	-0.2	-0.2
2. EXTENSIVE A+ (FRANCHISED)	1950	1660	18.00	18.00	10.8	11.7	2.5	2.6	-0.1	-0.1
3. EXTENSIVE B++ (FRANCHISED)	2240	1395	28.75	25.60	11.6	12.3	5.3	5.1	-1.1	-1.4
EXHAUST EMISSION INSPECTION										
4. IDLE (STATE LANE)	730	610	3.20	4.40	1.5	1.7	2.9	2.3	-0.0	0.1
5. EXTENSIVE A+ (STATE LANE)	1305	1360	10.10	12.90	7.9	9.6	2.9	2.3	-0.0	0.1
6. EXTENSIVE B++ (STATE LANE)	1475	1355	12.35	15.35	8.1	9.7	3.4	2.9	-0.3	-0.2

+ IDLE PLUS IGNITION TUNEUP, WITH DYNAMOMETER

++ IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

+++ COMPUTED OVER FIVE YEAR PERIOD

++++ BASED ON TOTAL VEHICLE POPULATION

A comparison of the cost per vehicle for the emission inspection strategy reveals a different trend. The costs for Region B are somewhat higher than for Region A. This can be attributed to differing mode emission distributions, pass/fail criteria and vehicle mileage accumulation rates between the regions. Additionally, the costs associated with the statelane inspection process also vary between regions.

The emission reduction performance reported for the two regions appears consistent. The one major anomaly involves the HC emission reductions predicted for the idle engine parameter inspection. The larger HC emission reductions reported for Region A is the direct result of maintaining RPM and timing for the 1966-70 group of emission controlled vehicles.

The optimal pass/fail criteria used in developing these results are summarized in Table 5-3. Note the trend to more restrictive pass/fail criteria for both the engine parameter and mode emission inspections. Because of the relative high weight given CO, only those parameters with large CO "leverage" were maintained (idle air/fuel and air cleaner). Misfire was also maintained because of its high cost effectiveness.

Figure 5-1 shows Region B emission time histories for HC, CO and NO_x, respectively, for both an idle and extensive "B" maintenance programs. The salient feature of these results is the low absolute emission levels for the three species. In general the emission profiles follow the same trend as for the Los Angeles region shown in a previous section and yield approximately similar emission reductions at the end of the fifth year. Whereas the influence of garage effectiveness and extent of voluntary maintenance have been examined in detail in the last section for the Los Angeles Basin they have not been assessed for Region B. One can assume, however, that variations in the level of maintenance performance should have a similar effect.

TABLE 5-3. OPTIMAL PASS/FAIL CRITERIA
FOR

PARAMETERS/MODE EMISSIONS	OPTIMAL SYSTEM PASS/FAIL CRITERIA*					
	PRECONTROLLED		CONTROLLED		POST 1970	
	PARAMETER DELTA	MODE EMISSION	PARAMETER DELTA	MODE EMISSION	PARAMETER DELTA	MODE EMISSION
o IDLE						
o IDLE CO (%)	0.04	3.4	0.04	2.9	0.04	2.9
o RPM	----	--	----	--	----	--
o IDLE CO (%)	----	--	----	--	----	--
o IDLE HC (PPM)	----	--	----	--	----	--
o TIMING (DEG)	----	--	----	--	----	--
o IGNITION						
o MISFIRE (%)	2.50	425.0	2.50	225.0	2.50	225.0
o NO _x	----	----	----	----	----	----
o INDUCTION	----	----	----	----	----	----
o AIR PUMP	----	----	----	----	----	----
o PCV (CFPM)	----	----	----	----	----	----
o AIR CLEANER (DEG)	15.	3.0	50.	1.0	50.	1.0
o CHOKE VACUUM KICK (IN.)	----	----	----	----	----	----
o CHOKE HEAT RISER	----	----	----	----	----	----

* As measured from manufacturers spec.

Key: — Vehicle not equipped

---- Parameter not inspected

-- Mode emission not inspected

AGGREGATED EMISSION TIME HISTORIES FOR DETROIT ENGINE PARAMETER INSPECTION

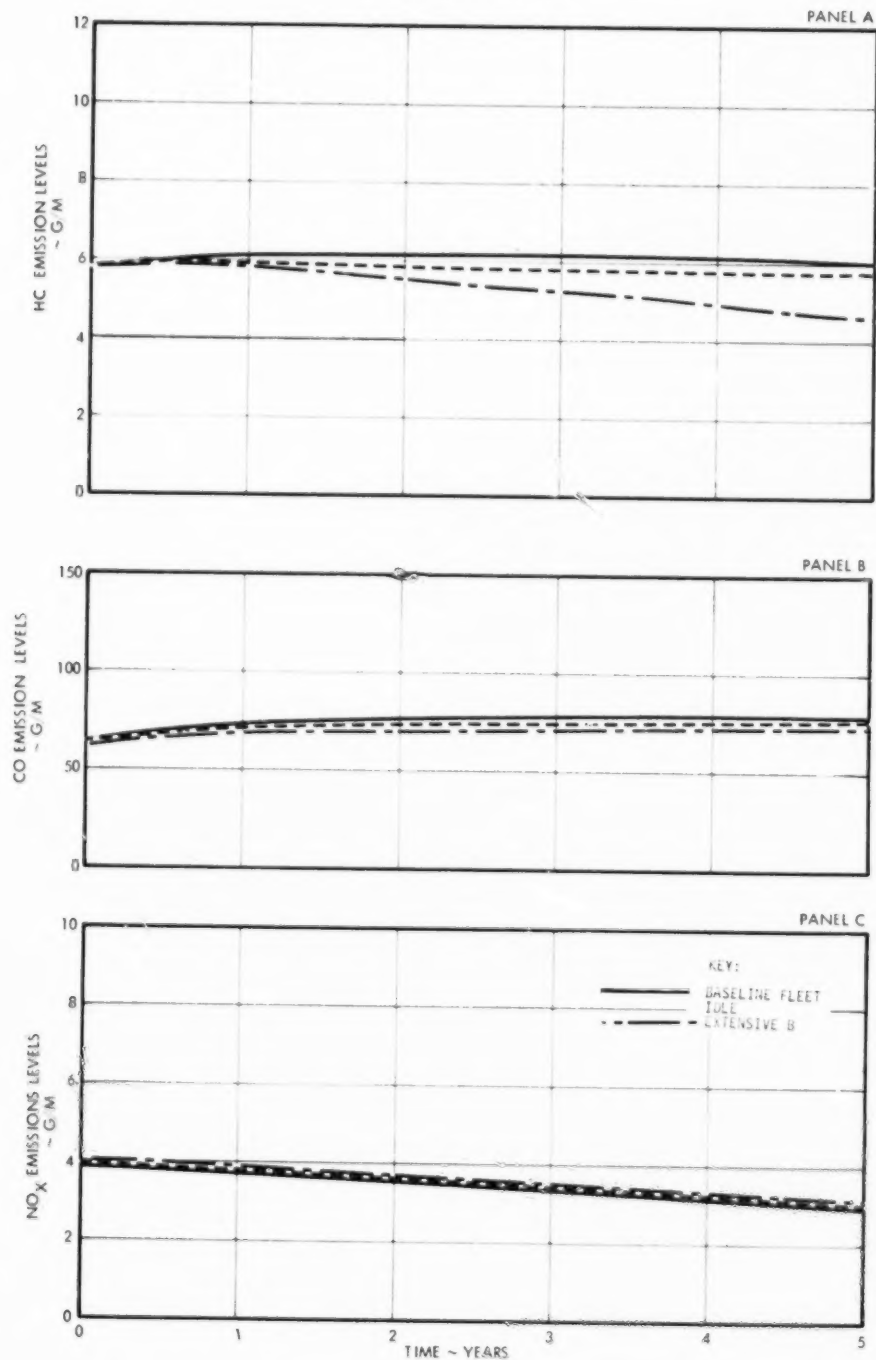


**FIGURE 5-1. EMISSION TIME HISTORIES FOR EXTENSIVE B
ENGINE INSPECTION**

In summary, the viability of mandatory vehicle inspection/maintenance depends upon the demographic and air quality characteristics of a given region. For regions characterized by uniform air pollution problems an exhaust emission inspection followed by an extensive "B" maintenance treatment yields the most attractive strategy in terms of emission reductions and program costs. This is especially the case if induction system maintenance effectiveness can be improved. For regions which have photochemical smog problems an exhaust emission inspection followed by an extensive "A" maintenance treatment appears to be the "best" strategy. One primary observation drawn from this analysis indicates the need for "customized" strategies. That is, a few key parameters should be selected which yield the highest emission reduction in terms of cost and the availability of reliable maintenance. Three other observations are also worth noting:

- Reduction of CO emissions can be achieved for considerably less cost than comparable HC emission reductions.
- None of the procedures identified to date are designed for reducing NO_x.
- Regions characterized by a high CO problem can benefit more by improve garage maintenance effectiveness than regions with high HC emissions.

6.0 STUDY CONCLUSIONS

The conclusions derived from this study are generally similar to those given in the Interim Report. This analysis differs from the previous one in the following regards:

- the entire vehicle population is considered i.e., uncontrolled vehicles, pre 1971 controlled vehicles and post 1971 controlled vehicles
- experimental data on the reliability of repair and maintenance durability is used for the first time
- the results are based upon the 1972 Federal Emission Test Procedure.

A summary of this current study is presented by major areas of investigation.

6.1 SELECTION OF OPTIMAL PROCEDURES

The results of the optimization for three levels of maintenance and the two inspection strategies are discussed below. These optimizations use a system figure of merit defined on the total annularized-discounted system costs per weighted ton of emissions reduced.

Emissions weighting factors of 0.6, 0.3 and 0.1 were applied for HC, NO_x and CO, respectively.

- 1) The results obtained using the new experimental data indicate a degradation in program performance when contrasted with the interim report results. This situation can be attributed primarily to three factors: 1) lower emission deterioration rates, 2) lower garage maintenance effectiveness, and 3) higher program costs.
- 2) The most cost effective inspection/maintenance procedure (figure of merit of 475) is an idle emission inspection in a state lane followed by adjustment of idle CO, speed and timing. Five-year average HC, CO and NO emission reductions are 1.5, 2.9 and -0.1%, respectively.
- 3) The most practical inspection/maintenance procedure (figure of merit of 1305) employs an idle mode HC and CO and loaded mode HC emission inspection in a state lane followed by the adjustment of the idle parameters and the repair of ignition system components causing misfire. Five-year average HC, CO and NO emission reductions of 7.9, 2.9 and 0% are achieved, respectively.

- 4) The largest emission reductions are obtained with a direct engine parameter inspection followed by an extensive B maintenance program performed in franchised garages. This program is eight times more costly than the most cost effective inspection/maintenance procedure, however, the CO emission reductions achieved are nearly double those obtained using the statelane emission inspection procedure with extensive A maintenance.
- 5) Emission inspection followed by the extensive A maintenance procedure is also cost effective when the statistically significant emission reductions at five years are used in the figure of merit in place of the predicted mean emission reductions.
- 6) The most cost effective parameters to maintain are the idle adjustments of CO, rpm, and timing; the ignition system components causing misfire; and restricted air cleaners and PCV valves.
- 7) Emission inspections in state lanes are usually more cost effective using any of the three methods used for calculating the figure of merit, primarily because of significantly decreased direct inspection costs.
- 8) Precontrolled vehicles are not a significant factor in the long term selection of inspection/maintenance procedures.
- 9) Fairly large inspection rejection fractions between 40 to 60%, are required to achieve reasonable emission reductions. This can be attributed in large part to the general ineffectiveness of garage maintenance.
- 10) Not all of the identified engine parameters are cost effective to inspect and maintain.

6.2 SYSTEM SENSITIVITY ANALYSIS

Sensitivity studies were performed to determine the influence of the input data and model assumptions on program performance. The previously discussed conclusions were generally found to be insensitive to these data and assumptions with respect to selection of the optimum procedures. The procedures performance values, however, are effected and in general were found to be sensitive to:

- 1) The effectiveness with which repair is made by a service organization. For example, if repair reliability were perfect, larger HC emission reductions and particularly larger CO emission reductions could be obtained.
- 2) The estimated rate of engine parameter deterioration, particularly idle fuel-to-air ratio and misfire.

- 3) The extent of voluntary maintenance as it is currently modeled. Obviously as vehicles are better maintained voluntarily, a mandatory program becomes less attractive. Based on existing owner behavior a voluntary program relying on improved garage maintenance emerges as an attractive alternative to a mandatory program.
- 4) The weighting factors assigned to the reduction of each emission specie, particularly when CO reductions are weighted heavily.
- 5) The frequency of imposed inspection and maintenance. Once yearly appears optimal.
- 6) Direct program costs such as maintenance, labor and user inconvenience as well as the cost of unnecessary maintenance.

6.3 REGIONAL IMPLICATIONS OF VEHICLE INSPECTION/MAINTENANCE

Two hypothetical regions were modeled having different air quality problems and vehicle populations. The economic-effectiveness of mandatory inspection/maintenance is most influenced by the emission reduction weighting factors assigned to various regions. Weighting factors which stress CO reduction generally result in a program that does little to control HC and NO emissions. However, large absolute reductions of CO occur, thereby resulting in extremely good figures of merit. Those procedures which adjust idle fuel-to-air ratio to specification are most effective for controlling CO emissions. CO emission reductions can be approximately doubled by maintaining components of the induction system but at four times the cost. Even larger improvements can be achieved if induction system maintenance effectiveness is improved.

In regions where photochemical smog is a problem and HC and NO_x emission reductions are heavily weighted, timing adjustments and ignition system repair become important. Little reduction of CO emissions is desired since NO_x emissions are adversely affected.

These regional results clearly indicate the requirement for a "customized" program designed to meet a specific air pollution problem. The arbitrary application of a program developed for one region to a region with differing air quality and demographic characteristics could yield counterproductive results.

REFERENCES

1. "The Economic Effectiveness of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions," Interim Report, TRW Systems Report in support of CRC APRAC Project No. CAPE-13-68, January 1972.